FUNETIC Board

Senior Design I
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University of Central Florida
Group 20

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1.0 Executive Summary

This paper documents the description, management plan, research, design, integration, constraints, prototype building, and testing of Group #20's senior design project - Funetic Board. The Funetic Board is a completely original idea inspired by the need to help people struggling with many different types of speech impairments. Its use will range from helping young developing learners, non-verbal communicators, people needing to improve their accent, to anyone just wanting to learn the nuances of the English language while having fun.

The Funetic Board user experience is the most important aspect of our design. We want to give every user an easy to operate and seamless learning tool. Having many LEDs light up in different patterns and colors is an important aspect to our design because creating a colorful and lively environment for our users will give our design an enticing and fun aesthetic. It is important that Funetic Board is aesthetically pleasing for all ages, since its main goal is to be a versatile fun experience for every user.

Some essential aspects of our design are an all-encompassing wood housing, integrated RFID sensors, a high-quality audio amplifier PCB, and an array of different colored LEDs all powered through a AC wall outlet. It will be important for our housing completely encase our electronics, as it should be suitable for young children to use. Integrated RFID sensors are essential four each phonetic sound to have a unique serial number corresponding to a new sound. The amplifier will be equally as critical, without high quality sound, there will be no way to convey each phonetic correctly and clearly. High quality LEDs add an important aesthetic while an AC wall outlet will make charging simple and accessible.

Reaching beyond senior design, Funetic Board has a promising future. It can be used in many different types of classrooms including reading, speech therapy, and ESL. Not only does the Funetic Board concept function in many different scenarios currently, if expanded it could have an even larger reach. One-way Funetic Board can be expanded is by having every sound in the english language incorporated into the design. This would make it an even more effective learning tool and could even turn it into a fully functional communication tool. Furthermore, Funetic Board could even be translated into many different languages making it an effective tool for almost anyone in the world.

2.0 Project Background

The next sections will introduce the Funetic Board by giving an overview of the project description, motivation, goals and objectives. This will include a brief explanation of the IPA, a speech term that is essential to our projects goals. After learning about IPA, our sample cards will be introduced, these cards are the aid between the user and the IPA dictionary. Furthermore, the section will move in a more technical direction outlining the house of quality, technical specifications and goals, and project decision matrix.

2.1 Project Description

The term Alternative and Augmentative Communication (AAC) encompasses the different communication methods used to supplement or replace speech. It describes any means of communication that is not traditional speech, such as speech output devices, gestures, sign language, and visual aids. Many studies have been conducted about Autism and AAC showing that using AAC with children helps them learn to speak. Right now, AAC available comprises of sign language, pictures, and visual boards. Funetic Board is a new and innovative AAC that approaches communication tools in a new way.

Funetic Board will be a CNC machined wood board with a row of aligned sockets. These sockets are placeholders for acrylic spheres to be inserted into. Each acrylic sphere will have a built in RFID module that links that specific ball to a specific phonetic sound. When a sphere is placed into any of the sockets, a colored LED will flash, and the sound associated with that sphere will be outputted to a nearby speaker. A programmed timer will move from left to right and the user will hear each sound associated with the spheres in the order they are placed. The Arduino will be used as the central device that will connect all components together. The Arduino will control the LEDs, output sounds, and RFID devices. The RFID's will be interfaced with the Arduino such that when a ball is placed the unique RFID tag will be sent to the Arduino to identify which sound is being placed. A team designed PCB will be used to power the entire device.

Example: The user will look through different index cards with different words, the IPA phonetic spelling of that word will be on the card along with a picture of the object representing the word. Figure 1 below shows how the board will look after executing the word “heard”.

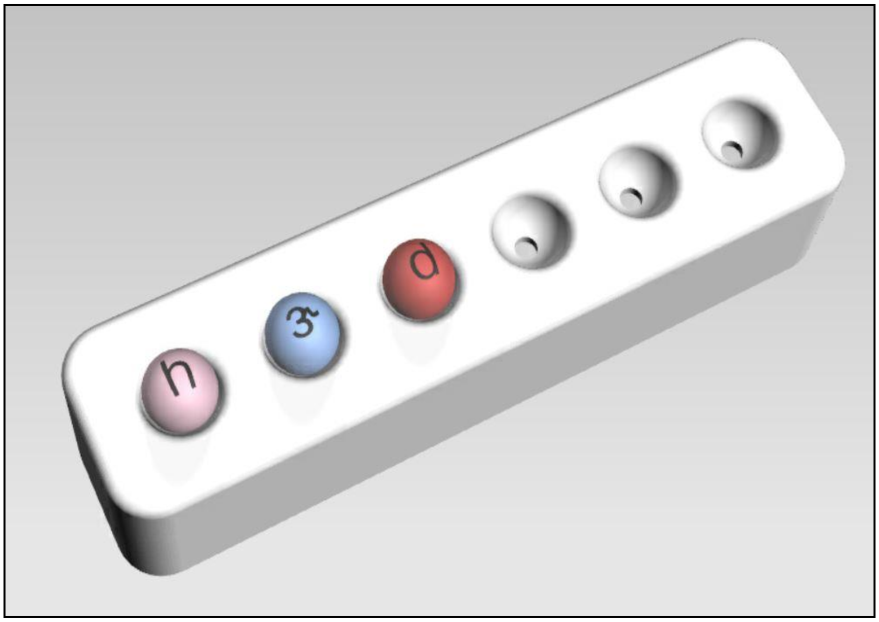


Figure 1 CAD Drawing for the Funetic Board

2.2 Project Motivation

Speaking is a tool that is easily taken for granted. Having a child that cannot communicate effectively can be alarming and frustrating. Many children, often labeled as “non-verbal” have so many things they would like to say but they are unable to. Others have an easier time attempting speech, but struggle with specific sounds and enunciation. The Funetic Board concept arose when thinking of a solution to help children with both non-verbal communication and articulation disorders. After delving deeper into the concept, its reach can be expanded to a much more diverse audience, from young children just starting out in sounds to ESL (English as a Second Language) learners needing to hone in on their pronunciation.

Another motivation for Funetic Board is its visual and audio aspects. It will be a fun and interactive experience for adults and children alike. There will be many different colored LEDs and fun sounds to give the overall project a fun and welcoming aesthetic. Adding visual components to sounds is a compelling way to make children feel like they are having fun while learning.

2.3 Goals and Objectives

The main goal of this project is to provide users with many different speech disorders a fun and interactive way of communicating. The Funetic Board needs to be easy to use and accurate. Ease of use is particularly important because having a hard time interacting with the device is detrimental to the user having a fun learning experience. Accuracy is another goal, users such as ESL learners need to hone in on very specific sounds without mispronunciation.

2.4 International Phonetic Alphabet

When it comes to phonetic dictionaries, there are many different versions that can be used to convey the same sounds. Every dictionary has their own way of phonetically spelling a word and although each way can be equally accurate, it is important to have a common convention when using phonetics to keep learning as simple and streamlined as possible. The Funetic board needs to be as easy to use to facilitate learning and keep young attention spans alert.

The International Phonetic Alphabet (IPA) is the most commonly used alphabetic system of phonetic notation. We chose this alphabet due to its information being readily available and its vast popularity. The IPA only represents the qualities of speech that are part of oral language: phones, phonemes, intonation and word/syllable separation. Other qualities of speech such as lisping, and tooth gnashing can be addressed with extended versions of the IPA. Furthermore, the IPA has two components, letters and diacritics. Diacritics are the little marks that go above letters to indicate accented words. We chose not to have diacritics in our project, since it would add too many balls to choose from and also over complicate the word building process. Since the Funetics board is aimed for learners with speech disabilities, using didactics would be too confusing and intense.

The IPA contains over 40 different symbols representing each phonetic sound in the English Language. If the Funetic Board wanted to contain every symbol in the alphabet, it would have to have over 40 unique balls for the user to choose from. Although ideally the Funetic team would like to have all combinations of words available to its users, we have budget and space constraints. For each phonetic sound that we introduce we would be adding another acrylic ball, and having 40 different balls to choose from for a seven-letter word could be overwhelming. Thus, we needed a way to decide which words and corresponding sounds will be chosen for the Funetic board to be the most educational under our budget and space constraints.

2.5 Sample cards

Since phonetic symbols are not common knowledge, the Funetic Board needs to contain supplemental material to aid the user for proper use. When the user begins to interact with Funetic Board, they will first need to select an index card, of their choice. This card will have three different ways to convey a word on it. The top of the card will be the english spelling of the word, the middle will be a picture that the word conveys and at the bottom will be the IPA translation of that word. Shown in figure 2 is an example of one of the 15 cards the Funetic Board will have to choose from.

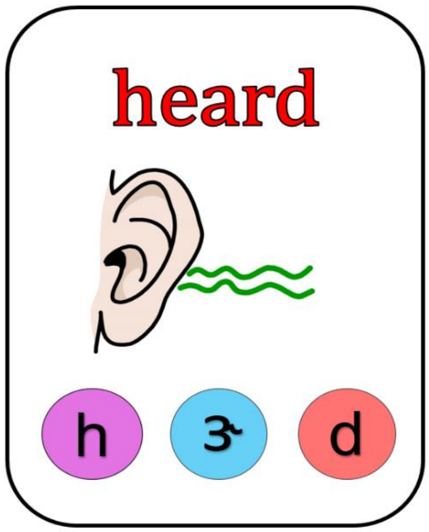


Figure 2 Sample Card

2.6 Choosing Sample Words for Cards

Researchers from Warwick Univlnersity claim that children need to learn just 100 words and 61 phonic skills to read the English language. They found that the benefits of learning new words exponentially decrease after the first 100 key words. These researchers also found teaching too many phonemes can have its downsides. For example, the word fridge wouldn't necessarily be a key word in teaching children phonetics because the "dge" sound is only found in 11 other words in the English language.

The Funetic Board will have an array of words and sounds that are handpicked to give the user the most benefit. After deliberating with our speech consultant we have constructed a list of the most useful sounds needed to build our Funetic board keywords. We used a few different strategies to find the most impactful keywords given our current constraints. Because we want Funetic board to be inclusive and multifaceted, we needed the most common sounds used in the English language to be incorporated into our design. Figure 3 is an English Phonemes chart showing the frequencies of each sound used in the English language [28].

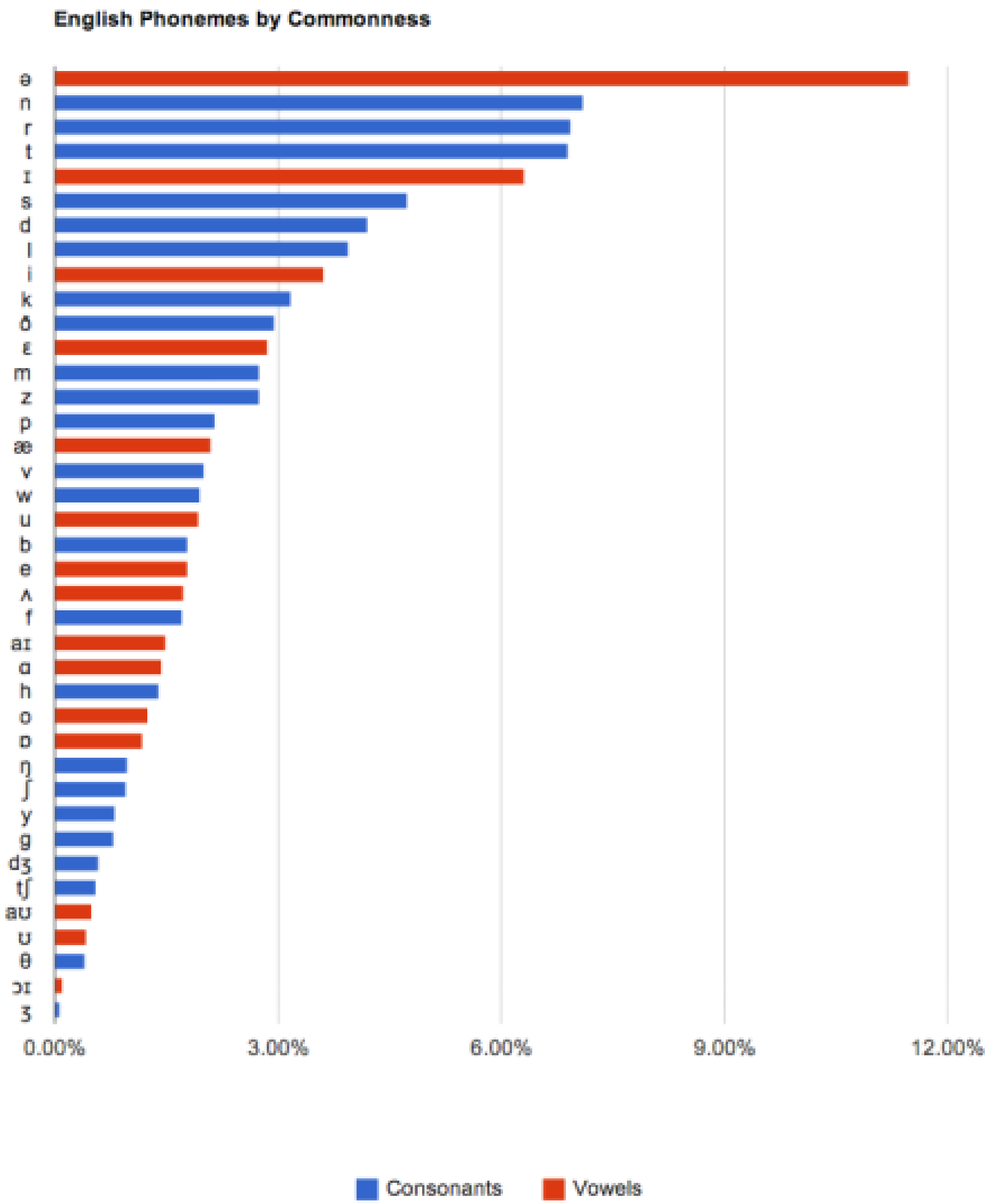


Figure 3 English Phonemes Frequency Chart (Permission Pending)

Not only do we want the most frequent sounds incorporated into our design, we also want common sounds that many people struggle with pronouncing. One of the most problematic sounds for ESL students and nonnative speakers alike is the /r/ sound. The English /r/ can take on many different vocalic properties. There are different types of /r/'s known as vowel r, vocalic r, and r-controlled vowel. Since the Funetics Board is an educational tool, its needs to take on these complex /r/ sounds in many different varieties without using too many balls to keep the user from being overwhelmed and confused. Table 1 shows the sounds that Funetic Board will be able to implement with the /r/ sound in all three sound types. For example, manner, her, and deer each use different pronunciations of /r/ while also sharing many other sounds and not being overly complex. These were excellent choices to be our Funetic keywords since they many of the same sounds we already had for other words.

Keyword	**IPA Transcriptionkisslo**
Ran	**r æ n**
Heard	**h ɝ d**
Her	**h ɝ**
Manner	**m æ n ɚ**
Deer – dear	**d ɪ r**
Ram	**r æ m**
Rook	**r ʊ k**
Sir	**sɝ**
Were	**w ɝ**
Rack	**r æ k**
Work	**w ɝ k**
Hinder	**h ɪ n d ɚ**
Winner	**w ɪ n ɚ**

Table 1

Although probably the most complex, the /r/ isn't the only sound that people struggle with. /l/ and /s/ sounds are also incorporated into our word choices, due to common mispronunciation of words like kiss and see. Table 2 below shows the sounds Funetic will implement that display the /l/ and /s/ phenomes. The /s/ sound is an especially important sound to emphasize because many people have frontal and lateral lisps. Having words like sand, sea, and kiss all emphasize the lisping sounds that children and even some adults struggle with. sound to emphasize because many people have frontal and lateral lisps. Having words like sand, sea, and kiss all emphasize the lisping sounds that children and even some adults struggle with.

Keyword	IPA Transcription
Kiss	**k ɪ s**
Look	**l ʊ k**
see – sea	**s i**
Sand	**s æ n d**
Sack	**s æ k**
Miss	**m ɪ s**

Table 2

Table 3 below shows the other assorted sounds that many people struggle with. Table 1, 2, and 3 are all words that will be considered the index card keywords being used in our Funetics display. There will only need to be 15 different acrylic spheres to execute these words. Table 3 has some chosen words encompass many different aspects of language while sharing similar sounds to keep our ball count low and project reach high.

Keyword	IPA Transcription
Hand	**h æ n d000000**
Man	**m æ n**
Woman	**w ʊ m ə n, w ɪ m ə n**
would – wood	**w ʊ d**
Week	**w i k**
Wind	**w ɪ n d**
Hook	**h ʊ k**
Hood	**H ʊ d**

Table 3 Example Words for the Funetic Board

2.7 User Interaction

The user interaction is how the user will interact will the Funetic Board. This interaction process should be simple enough for a child to use. This process will start with the user referencing the index cards to choose a word. The user will then place a ball with the corresponding phonetic sound into the leftmost available socket. This will then prompt the LED to light up the phonetic ball. The individual phonetic sound will then be played from the speaker. Shown in figure 4 has is the block diagram the shows how the user will interact with the Funetic Board.

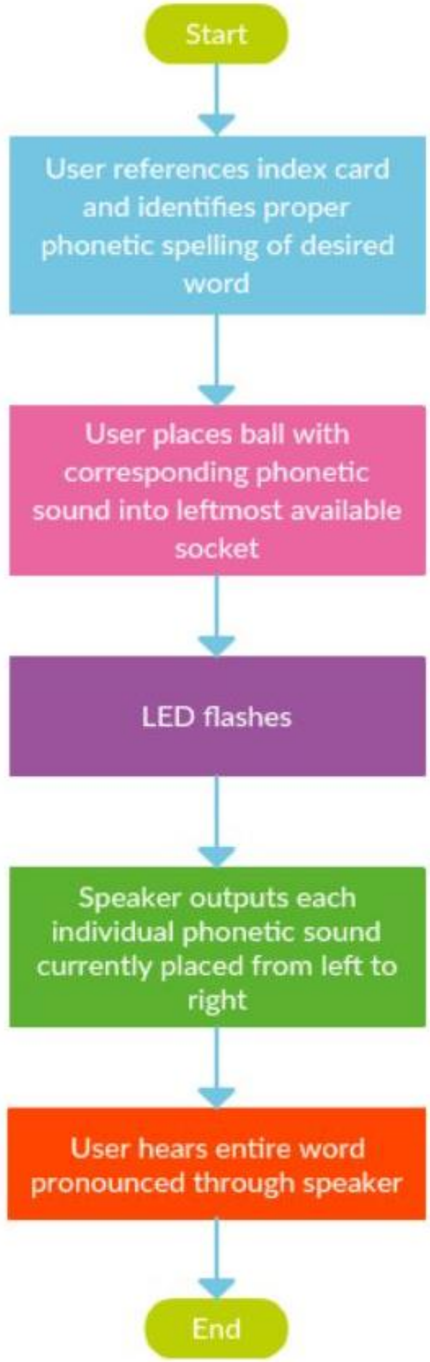


Figure 4 Shows User Interaction with the Funetic Board

2.8 House of quality

When starting this project, a house of quality was designed to show the tradeoffs between marketing and engineering requirements. This is useful, so requirements and concepts can be identified early on in the planning and design phase. The house of quality for the Funetic Board is shown below in figure 5.

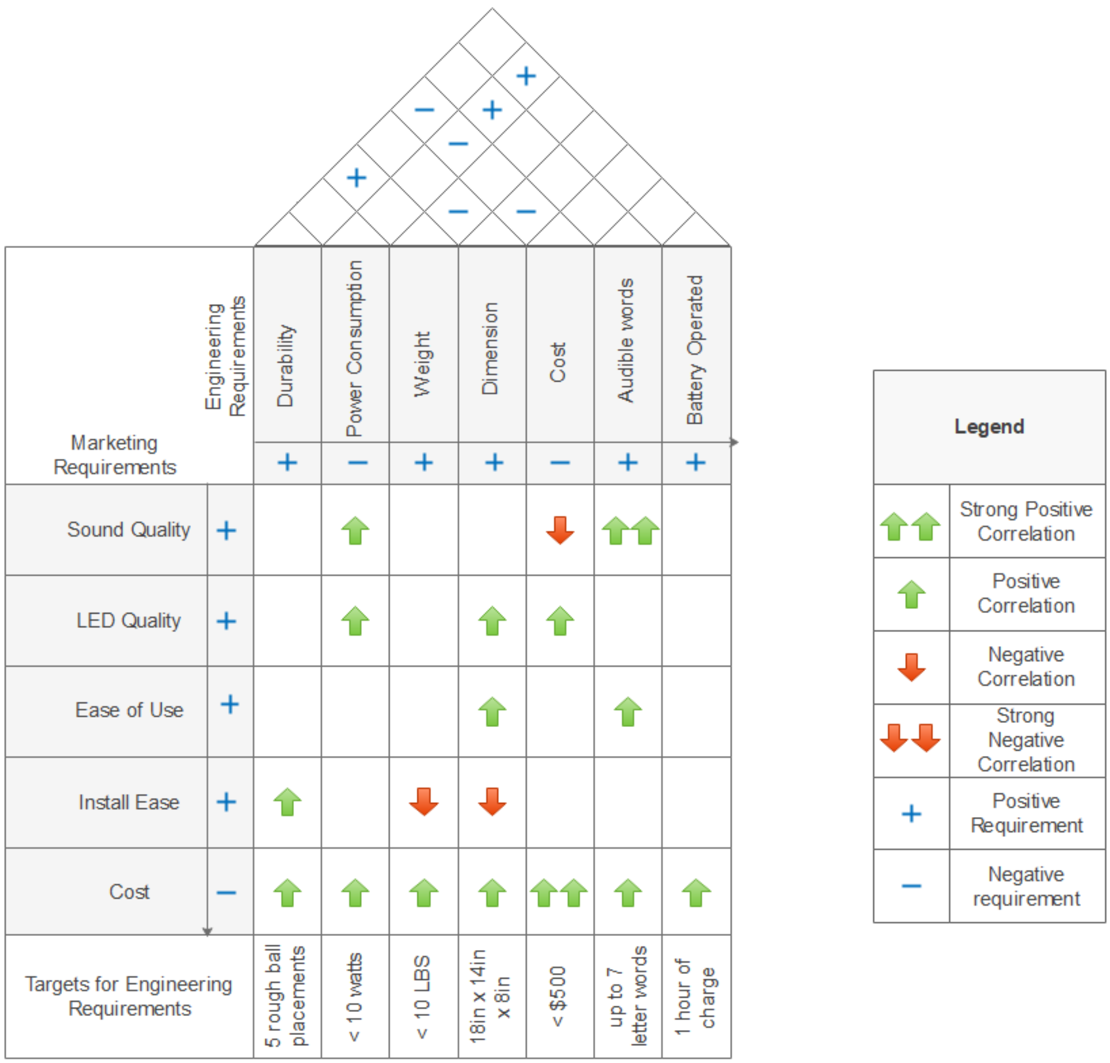


Figure 5 House of Quality for the Funetic Board

The market requirement with the largest impact would be the cost of the overall product. If the product is priced highly it might not be affordable to a wide market of users. If the product is priced with a low cost, then the quality of the product might not be worth the purchase since it is geared toward a learning tool. The cost to build the Funetic Board is likely to be in the range of $700.

The install ease and the ease of use of the product are important for the marketing requirements. This is because after buying a product the purchaser then needs to install, setup, and use the product. If the task of installing the product deems to difficult the customer might return the product before ever trying it. Also, if the product is not fairly easy to use that could be another reason for the customer to return the product. If these marketing requirements are satisfied, then the product will have a greater chance at being successful on the market.

The LED and sound quality are important marketing requirements considering that this product is aimed at being a learning tool. The LED quality is important so that the user is able to see that the ball has been identified as being placed. The sound quality is important so that the phonetic pronunciation of the words are able to be heard clearly.

The engineering requirement with the most impact would be durability factor. The durability will increase the dimensions, cost and the weight. When designing the product, the durability plays a role in the dimensions because if the overall size of the product is too small it is more likely to be damaged but the user. The material of the housing for the PCB, wiring, and phonetic balls need to be durable enough to withstand minor roughness. Which makes the dimensions larger compared to if flimsy materials would be used to design the product.

Another significant engineering requirement would be the cost. The more the product cost to build the more the product will be on market. Also since this is being made as a senior design project by four students the end cost will come out of our pockets. The idea is to create an ideal product with a manageable cost

2.9 Technical Specifications and Goals

The technical specifications and desired results for this project can be split into 3 categories. Our project has branched them into functionality requirements, display requirements, and design requirements.

- Functionality
  - The board should be able to distinguish between the 26 English alphabet letters
  - Produce audio at a reasonable volume
  - Correctly pronounce real completed English words
  - Begins to speak the presented word at the push of a button
  - Low power requirement
  - Ability to run on batteries
  - Maximum power usage 10 watts
  - One charge last at least 2 hours

- Display
  - Cue cards to display spelling

    - Clear white balls with letters displayed outside and possibly illuminated by LED lights
    - White sturdy board that contains scanners and LEDs

- Design
    - Use of Arduino micro controller
    - Durable material to withstand heavy usage
    - Use of RFID chips assigned to letters of alphabet
    - Our board should be kept light weight as it is geared towards kids
    - 16 inches by 14 inches by 8 inches

These are currently the most general requirements we decided to make our project within perform at a reasonable result. The functionality category allows us to ensure we can acquire a good translation from user input to device output. It makes sense for the device to be as portable as possible since its intended use is geared towards a younger audience as sitting in one place for a long period of time seems to be quite a challenge. Due to portability, batteries and optimal life time of operation was necessary. We wanted to keep it as simple as possible by using an easy push button for activation. The display category was constructed together with the intention of trying to be as friendly and eye pleasing as possible in hopes of attracting attention to be approachable and spark curiosity. The design category was put together with the idea in mind of it being able to handle being dropped, something dropped on it, or somehow damaged in any way and still able to be fine. With all the specifications met, we should have a fully functioning and desirable product.

2.10 Project Decision Matrix

Upon coming up with our final project decisions, we encountered various options along the way. Initially, there was debate on what project we exactly wanted to do. A smart bike sensor was a good candidate as there were a lot of similar projects and open source sensors we could put together and incorporate to construct something better and more simplified. Additionally, we had the option of creating a smart pancake maker. The intention of this project was to allow the creation of fully automated high precision detailed art images made out of pancake batter.

Ultimately, we went with the smart LED grid board that turned into “Funetics”. Once deciding on our project, it came down to deciding how we wanted to implement the idea of Funetics that was within our reachable abilities. There were debates on what functionality the grid board would produce, what kind of microcontroller to use for it, and how we should detect user inputs into the grid board. With the resulting decision to recognize spelling and produce speech, we needed to decide on how long we want to make our words as the number of characters can drastically change the amount of possible combination of words it will have to correctly output and size of our grid board. Figure 6 below demonstrates the decision path traversal.

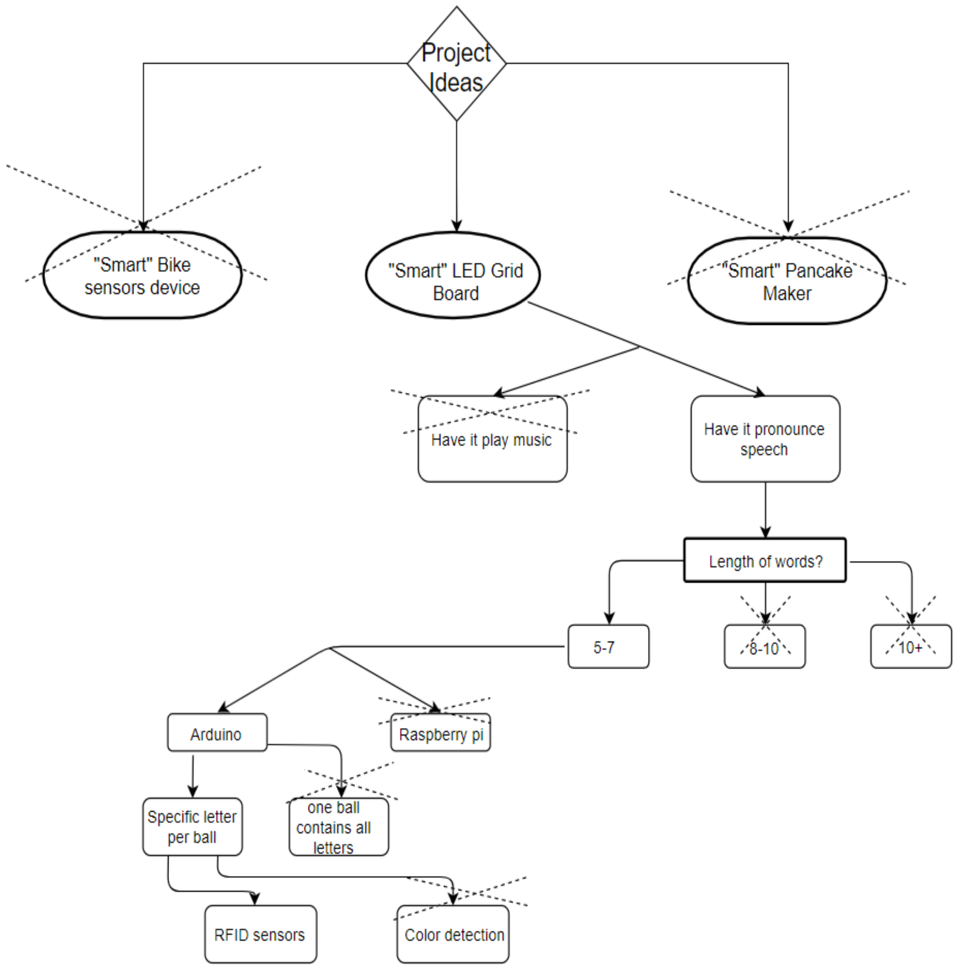


Figure 6 The Initial Project Decision Matrix

3.0 Project Management Plan

The project management plan is a procedure in which each group member has been assigned a primary or secondary responsibility for an aspect of the project throughout its research and implementation phases. As a group we will hold each other accountable to reach milestones by their deadline in order to design a final product that contains an effective design. Each group member will make contributions in each aspect of the design, testing and integration with a focus on a specific field.

EJ, a computer engineer, will mainly focus in software programming and integrating aspects of the Arduino microcontroller. Meychele, a computer engineering will mainly focus on designing the software for the on-board components and collaborating with our speech consultant. Daniel, an electrical engineer, will primarily focus on the wireless sensors and power supply for the onboard components of the design. While Maureen, an electrical engineer, will primarily focus on the design and integration of the audio PCB board.

We will outsource our PCB schematic to a manufacturer for them to make the board after testing our design and integrating our components with a breadboard. As a team we have a common goal of delivering a reliable, low power consumption product that performs precisely and enhances the user's audio experience.

3.1 Milestones

These goals along with a due date for each is crucial to follow to meet expectations in a reasonable time period. The first table is the description of the goals with start and end date for Senior Design I which ends the first week of December. The second table is for Senior Design II. Senior Design II starts in January and ends in May. The goals for SD1 and SD2 are significantly different since in SD1 the idea is to research plan and prepare for SD2 where then we put the research to test and implement the design to get a working prototype.

3.1.1 Milestones Table

The milestones tables for senior design I and senior design II will provide a layer of structure that will outline the most important tasks. These tables will provide as a reference to guide the group through accomplishing the tasks at hand. These milestones tables will be used to keep up with remembering which milestones have a higher priority. Table 4 lays out the milestones for SD 1 and table 5 does the same for SD 2.

Description	Status	Start Date	End date
Brainstorming ideas	Completed	08/21/2017	08/31/2017
Project selection	Completed	08/31/2017	08/31/2017
Initial research	Completed	08/31/2017	09/08/2017
Choosing Microcontroller	Completed	08/31/2017	09/08/2017
Dividing tasks	Completed	09/06/2017	09/06/2017
Divide and conquer	Completed	08/31/2017	09/21/2017
Table of contents	Completed	09/21/2017	09/27/2017
Update Initial Doc.	Completed	09/27/2017	10/06/2017
Power supply	Completed	9/20/2017	11/01/2017
PCB design	Completed	9/20/2017	11/01/2017
60 page paper	Completed	09/21/2017	11/03/2017
100 paper paper	Completed	09/21/2017	11/17/2017
120 page final paper	Completed	09/21/2017	12/04/2017
Order Parts and Materials	Completed	09/21/2017	12/04/2017

Table 4 Milestone Table for Senior Design I

Description	Status	Start date	End date
Build prototype	Not started	TBD	TBD
Program prototype	Not started	TBD	TBD
Test prototype	Not started	TBD	TBD
Finalize prototype	Not started	TBD	TBD
Peer presentation	Not started	TBD	TBD
Final paper	Not started	TBD	TBD
Final presentation	Not started	TBD	TBD

Table 5 Milestone Table for Senior Design II

3.1.2 PERT Chart

The Pert Chart is a project management tool the group will use to schedule, organize, and coordinate tasks within this project. This chart will help the group stay on schedule to help the project progress successfully along the projected timeline. Figure 7 shows the Pert Chart for SD 1 and Figure 8 shows the Pert Chart for SD 2.

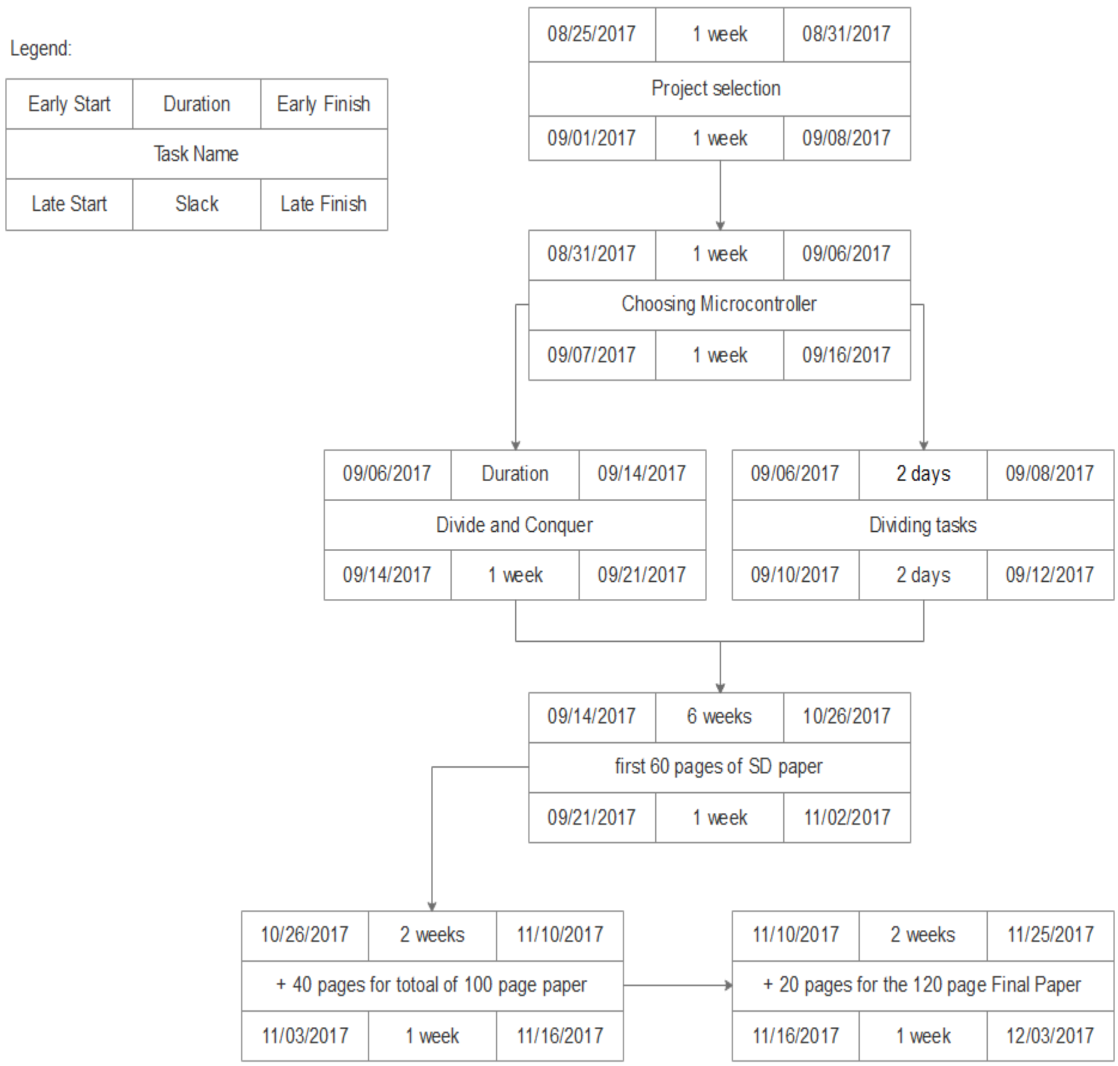


Figure 7 Pert Chart for SD 1

SD2

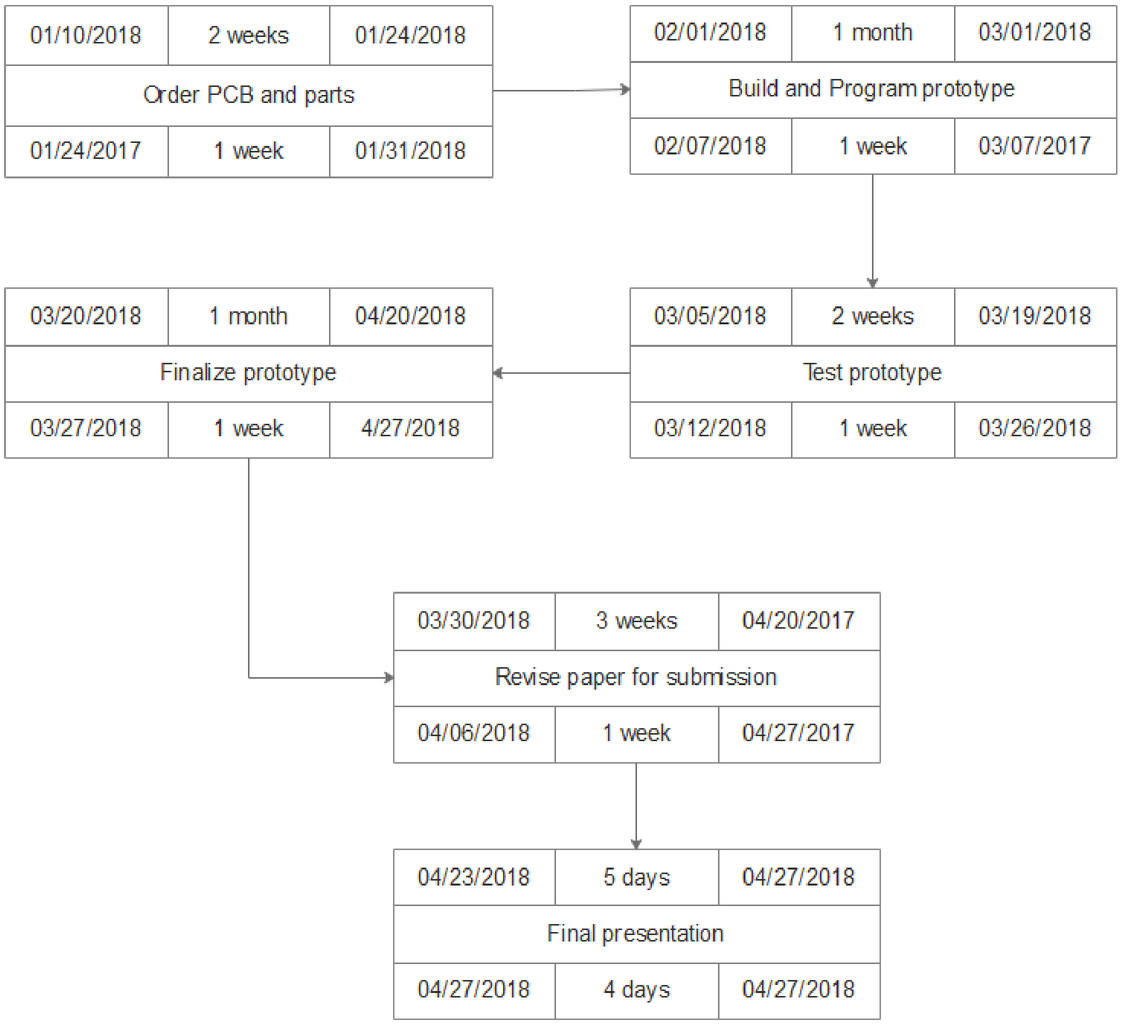


Figure 8 Pert Chart for SD 2

3.2 Team Organization

Being organized and keeping to the timeline will be a crucial part of this project, being organized will allow the group to move fluently throughout the project's design process. Creating a plan and sticking to the strict timeline will lead our group to a successful project at the end of Senior Design II. Using the process described in the project management plan will simplify the entire project's process

3.2.1 Group Dynamics

The design of the project will be distributed between two computer engineering majors and two electrical engineering majors. The two CpE students will focus on choosing and implementing a microcontroller and designing software for PCB board components. The two EE students will focus on choosing and implementing the hardware aspects of the project such as the sensors, speaker, and power supply.

During the research, design and implementation of the project, the group will be communicating using email, social media, and the app slack created for the project. As a group we decided to meet for sure once or twice a week with other arranged meetings if needed. Group meetings will be held before lecture on campus. Another mechanism that we found useful is Google drive, which provides features that allow for online group discussions, merging of documents and even allows group members to simultaneously modify a document. Utilizing these tools will allow our group members to stay in contact with each other with the ability to choose from different methods of communications.

3.2.2 Applicable Standards

For the required documentation, all documents will be made using the following requirements that will provide useful for merging documents from each individual. The documents will be created in Microsoft word with Arial font with a font size of 12. For the headings, we will utilize the same font but with a larger font size of 20 and the text will be bold. For the margins, all surroundings margins will be 1" around with the exception of the left margin. Which will be set to 1.5" to allow room for bindings, if needed. All documents pertaining to the project will be stored in the group google drive folder named senior design, while any change or update made to documents will be automatically saved and history of changes will be stored with google drive.

3.2.3 Tools and Computing Environment

Funetics will depend on the software for converting and transitioning our phonetic spelling balls collection into an audible real word. We will be describing the programming languages and environment we finally chosen and close considerations. Each language had their advantages and disadvantages with the set of algorithms and libraries they had to offer.

3.2.3.1 Programming Language Comparison

When starting the project management plan, one of the things that needed to be decided upon was the programming language that we would be using to program the Funetic device. This language needed to be a commonly known language. The common languages are python, C/C++, and java. These languages needed to be compared to see the benefits and detriments of each language. In the following sections different languages will be compared and one will be decided upon for use in programming the Funetic device.

3.2.3.1.1 Python

Talking to Arduino through a serial interface was pretty trivial to do in Python. On Unix-like systems you can easily read and write to the serial device like it is just a file. Thankfully, there is a wrapper library that PySerial that operates well on all operating systems. Upon installing PySerial by using a simple pip install from the python command prompt, reading data from Arduino became just as straight as using anything else. The hard work was already done by importing the library and using functions to set up the initial serial start up. As long as you had a version of Python 2 or higher, writing data to the Arduino was just as easy. But if you were in Python versions 3 or higher, it may be problematic since by default all strings are converted to Unicode. Arduino needs the data to be converted to bytes. Even though better versions exist, optimally it was better to work using a version of Python higher than 2 but less than 3. Using the Serial library to create the setup function then looping infinitely to print the string “I blinked” with a one second delay in between each print.

3.2.3.1.2 C/C++

This is the most common and standard language to use when working with Arduino as that is the compiled language that interacts with everything. The Arduino language being nearly identical subset of C/C++ functions is just calling the corresponding equivalents by automatic generation of function prototypes then passes directly to the compiler.

3.2.3.1.3 Java

The JArduino (Java-Arduino) library provides a Java API to control an Arduino using the serial port which makes it easy to code using any IDE and with functions and classes for every use. The RXTX Java library also provides a standard Java communication API to the serial port. Setting up the libraries are platform independent and both relatively easy to do. There are enough APIs and libraries out there that the conversion to using Java became common and popular with lots of example codes and references.

Ultimately, programming the software would be easiest to do in the already set C/C++ language as we can accomplish everything we need to do for the project scope given by C and it has good functionality to experiment with using the vast number of libraries and headers. There would be no need to go through conversions or additional set up if using other languages or communicating primarily through the serial port.

3.2.3.2 IDE Comparison

The IDE is a tool that programmers use to write and test the software. The IDE that will be decided upon for use is important to do research on before using one since different IDEs offer different tools. Familiar IDEs will be compared along with unfamiliar IDEs, so a decision can be made upon that will be beneficial to the software programmers on the team.

3.2.3.2.1 Arduino IDE

The Arduino IDE contains a text editor for writing code, a command console, a text area, and tollbar with functions for common algorithms. The software goes hand and hand with the hardware since it is made by them. It is great for beginners to introduce programming such as C/C++ due to its simplicity. But for those with some experience, the IDE is quite unimpressive as it lacks a lot of good high-end features. This tool is pretty limiting to the extent of those trying to excel such as using auto-complete features, refactor codes, external symbol browsing. It still offers direct functionality to your devices and nothing extraneous for those with a plan.

3.2.3.2.2 Atmel

Atmel Studio combined with Visual Micro enables the creation of any type of Arduino project to be developed, compiled, and uploaded to any Arduino device. It makes almost an identical share of sources and tools to the Arduino IDE but the IDE itself is different. It supports a combination of multiple ino file sketches and CPP source codes per project. The compiler is a simple all-in-one one-click compile and upload at very fast speeds.

3.2.3.2.3 PyCharm

PyCharm by JetBrains is an intelligent code editor for the use of primarily Python that provides those with auto code completion, real-time code errors and syntax quick fixes. It includes features of code refactoring and rich navigation abilities. PyCharm is most notable for its huge collection of tools and plugins. This is exceptionally useful for us since there exist a plugin for Arduino that enables Arduino CMake integration compatibility.

3.2.3.2.4 CodeBlocks

CodeBlocks Arduino IDE is a customized distribution of the original open-source Code::Blocks IDE specifically enhanced for Arduino development. For those more demanding software developers, it offers everything a modern IDE should have like code folding, code navigation, code completion, compilation, and uploading to Arduino. The distribution includes latest code files from Arduino, the standardized libraries, an AVR toolchain, a serial terminal, the Builder for Arduino, and the most unique feature, a high-level API Arduino simulator.

3.2.3.2.5 Eclipse

Eclipse is a free, powerful, and full-featured development environment that can be used to work with AVR and Arduino. Combined with the WinAVR compiler and Eclipse AVR-plugin, developing projects becomes an ease. Obtaining the Arduino core library can be done by simply compiling the library contents from hardware/cores/Arduino directory directly into the project.

Ranking most useful IDEs to use from worst to best, the traditional PyCharm would probably be the least beneficial due to our project’s scope. Then, Arduino IDE would be next least useful since it is made for simplicity and has a lot of limitations. Atmel provides nearly the identical things as Arduino IDE and then some, so it gives it an edge over the Arduino IDE. CodeBlocks has a lot of notable features since it is a customization solely made for Arduino and focuses a lot of enhancing a better experience and makes it a great runner up and not far off. But, Eclipse will have to take it in the end as it provides everything with no limitations and ease of use. It makes a great software environment for the Arduino programming.

3.3 Budget and Financing

The Funetic Board estimated cost will be about $700. We have chosen to not seek a sponsorship, due to wanted to keep the intellectual property within the Funetic team. Parts will need to be purchased for the testing purposes and also for the design phase of the project. The final price point will be divided evenly amongst the 4 group members. The project budget for parts is shown in table 6.

Item	Part Number/ Vendor	Quantity	Cost
Arduino UNO	Amazon	1	$35
SD memory card shield		1	$7
Audio Amplifier	LM386N-1 Amazon	1	$7
Adafruit wave shield	Arduino store	1	$25
Wood Board	TBA	1	$50
CNC Machining	TBA	1	$150
RFID system	TBA	1	$50
PCB manufacturing	TBA	1	$100
Wires and components	TBA	1	$50
Acrylic Balls	TBA	20	$50
LEDs	TBA	10	$10
Speaker	Amazon	1	$12
Structure materials	TBA	1	$100
Equipment	TBA	Solder, tools, etc	$0
Documentation printing	TBA	1	$50
Lithium Ion battery	Amazon	1	$15
		Total	**$715**

Table 6 Project Budget

3.4 Integrity Testing

To test the integrity of the components, a test plan will be constructed and followed. Moving forward this will assure the team that all of the parts and devices work as expected according to the corresponding datasheet. These testing procedures need to be extensive and must include testing of individual tasks. This will allow the team to make sure accurate readings and results are being obtained. The overall project system will also be tested this will establish that all components perform as needed together. System testing will be discussed in the Testing section of this document, which is in section 8.0.

The initial act in constructing the integrity testing plan is to establish the individual characteristics outlined in the datasheets to test basic operational performance. Doing this it will allow the group to keep the testing organized and will also allow for utilization of specific test cases. When test cases are created it will be necessary to know the impact and effect of each case. Knowing this will allow the for the primary functions to be secured first.

The subsequent sections will outline the projected integrity testing plan. For the system and integration test procedures with expected results go to the Testing section of this document in section 8.0.

3.4.1 Microcontroller Testing

The microcontroller will be the first instrument we will apply integrity testing too. While doing integrity testing on the microcontroller, standards such as data rate, data integrity, environmental testing, as well as a few other select tests will be checked. To be able to validate the integrity if the microcontroller there must be a set of fundamental tests. These tests will validate a basic level of operational performance as outlined by the datasheets. The constructed test are shown in table 7.

Microcontroller Testing	
Test Objective	Check if input is received
Test Description	This test will determine if the microcontroller is functioning as expected and receiving input from all of the sensors.
Test Objective	Stress Test
Test Description	This test will have the system run for an lengthy period of time to exceed regular operating times. We will observe temperature, speed, and reliability.
Test Objective	Environment Testing
Test Description	This test will run the microprocessor in conditions outside of its “normal” operating range. We will run it for an extended duration in cold, heat, and as well as through dirt or dust.

Table 7 Microcontroller Integrity Test Procedures

3.4.2 RFID Module Testing

During the RFID integrity testing, there will be tests to verify data transmitted between devices. The data rate and distance at which our RFID module can operate effective and consistently will be tested. The integrity tests developed for this application can be seen below in Table 8.

RFID Testing	
Test Objective	Check if input is received
Test Description	This test will determine if the microcontroller is functioning as expected and receiving input from all of the sensors.
Test Objective	Interference testing
Test Description	This test will determine the ability of the RFID module to resist interference and transmit our data successfully.
Test Objective	Distance Testing
Test Description	This test will test the levels of signal strength at various distances.

Table 8 RFID Integrity Test Procedure

3.5. Project Development Life Cycle

The project development life cycle consists of 4 main phases. These four phases are known to most as the initiation phase, planning phase, execution phase and the final phase. The first phase consists of knowing the project requirement specifications. Phase two consist of the research that needs to be done for the project. The third phase involves the design, implementation, testing, and installation for the project. The final phase consists of the maintenance for the final project. A block diagram for the project development life cycle is shown in figure 9.

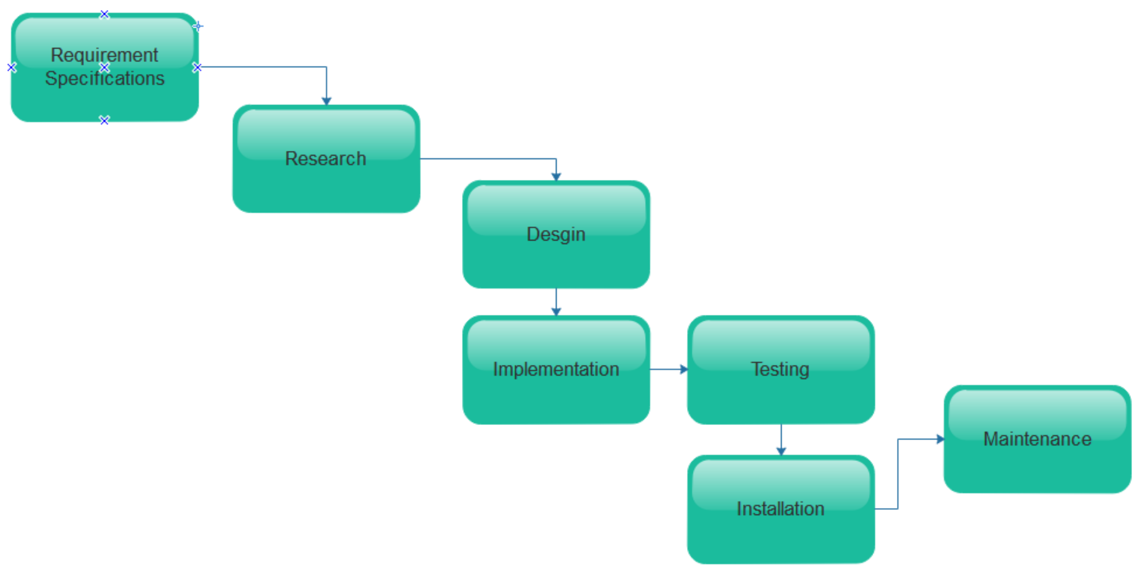


Figure 9

4.0 Research

Researching the different aspects and requirements for the project must be done before starting the design procedures. It will be helpful to research as much as possible about similar projects and aspects of components we intend to include in the Funetic Board this is to give the team an understanding of the options that should be considered when designing the device. It will be important to be knowledgeable in the knowing how much power the devices components will need to be supplied. It will also helpful to have a understanding of how to supply the correct amount of power to the different components.

Research will be done for the following topics, finding a microcontroller, speaker system, LEDs, housing, battery, and RFID modules. These topics will be thoroughly researched until a decision is made for each product to include the best option researched into the project design. Each different option will be decided upon by evaluating parameters such as dimensions, capabilities, and convenience.

4.1 Microcontroller

The first decision was to decide between using a microcontroller or just using a microprocessor, so this was the first task at hand. The Microcontroller (MCU) option would have been an easier choice over the use of microprocessor so that we could save time creating hardware from scratch with so many MCU available with open source hardware and software the decision was clear that the smart choice would be to use a MCU. The decision was to be a microprocessor, so we could demonstrate a complex PCB design. Although a microcontroller would still be needed for the testing phase to make sure the device works as intended before creating our own PCB using the microprocessor from the microcontroller chosen. The most popular MCUs are TI MSP430, Arduino Uno, and Raspberry Pi. Figure 10 shows some of the differences between microprocessors and microcontrollers [30].

When choosing which microcontroller to use it can be overwhelming with so many choices available. So, the first deciding factor is to know the technical specifications that the project is going to need to have. Then further deciding factors when choosing the MCU was made simpler by making a list of the required hardware interfaces, examining the different software architectures, identifying memory requirements, looking at cost and power constraints, and looking into compilers and tools.

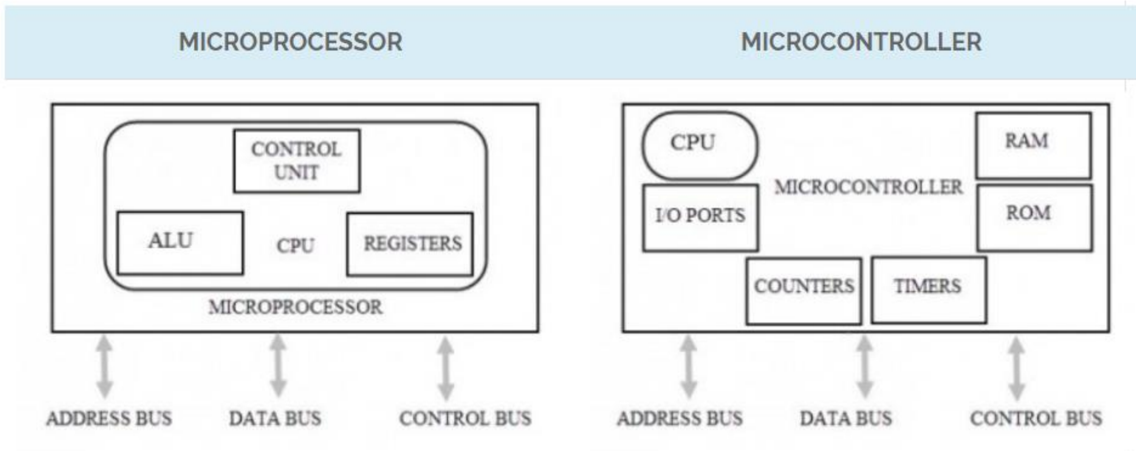


Figure 10 Comparrison Between Microprocessor and Microcontroller Reprinted with permission from ElectronicsHub.org

4.1.1 Microcontroller Comparison

The three most popular microcontroller platforms, researched by the team, will be compared and discussed in this section. These three platforms include the MSP430, Arduino, and the Raspberry Pi. When making the final decision a few of the things that will be taken into consideration including the performance, memory, peripherals, I/O packages, operating voltage, speed, and power consumption.

4.1.1.1 TI MSP430G2

The Texas Instrument MSP430G2 microcontroller is a value product utilizing the MSP430 core, and is one of the more capable microcontroller from TI at the price point being considered. Given the raw performance capabilities of it and considering the price of the 430G2, this is an attractive option for the Funetics design team. This is also the microcontroller that the team has the most experience with. The MSP430 platform is the microcontroller that is utilized in some of the classes taken by the design team. This is a reasonable incentive to go with this microcontroller given the experience of all team members. There are a variety factors worth considering with this microcontroller; an internal clock as well as support for external clocks, a relatively simple instruction set, a lower power requirement, multiple Input/Output pins, and the ability to utilize UART, SPI, and I2C communication protocols.

One of the key selling points of the MSP430G2 is its low power draw. When in power saving mode it can use as little power in the milliwatt range. With the Funetics device utilizing a rechargeable battery for a power source, this is an attractive feature. This power saving mode is something that would need to be implemented within the software program of the device. Implementing this will require more time from a programming aspect, but depending on the results of battery life tests the power saving could very well be something desirable to implement. Texas Instruments provides extensive documentation on the MSP430, including the instruction set, which will greatly aid in the process of implementing the power saving mode.

Given the need to utilize devices external to the microcontroller in the Funetics device, the capabilities of the Universal Serial Communication Interface (USCI) are important to note. The MSP430G2 is capable of supporting UART and SPI, with limited support for I2C. This is a hardware solution for selecting which communication protocol the user wishes to implement. This is much more convenient than having to implement any via software. Doing it through software would be costly and troublesome due to the utilization of wireless RFID signals in the Funetics device, which would complicate signal timing.

The MPS430 has built in 16-bit timers, up to 24 I/O capacitive-touch enabled pins, a versatile analog comparator, and built in communication capability using the universal serial communication interface. In addition, the MSP430G2x53 family members have a 10-bit analog-to-digital (A/D) converter. The only major limitation as far as this project is concerned is that there is no external memory bus, so the maximum memory is contained to the on-chip memory. The specifications for the MSP430G2 can be seen in table 9.

Clock Speed	16MHz
RAM	512 bytes
Storage	16 KB
Input Voltage	3.6V
Minimum Current	Not provided
Digital I/O Pins	16
PWM Pins	n/a

Table 9 MSP430G2 Specifications

4.1.1.2 ATmega328/Arduino Uno

The Arduino Uno is one of the most widely used development boards in the world, and as such the ATmega328 is a prolific microcontroller. It is utilized by students, hobbyists, and professionals. A variety of factors make this chip one of the more popular around. The price point is competitive with the likes of Texas Instruments and other microcontroller manufacturers. The extensive libraries that Arduino provides gives those programming on their products a wide variety of tools to take advantage of right out of the gate. The open source nature of the Arduino platform has resulted in a flourishing community that develops and shares their own creations. In many instances there are multiple people in the community that have already done extensive work in any given field/specific project and have provided detailed documentation on how to accomplish tasks. Finally, the feature set of the ATmeg328/Arduino Uno provides a wide variety of options that most anyone looking for a microprocessor will be happy with.

The ATmega328 is part of the Atmel AVR microcontroller family. It has a data-bus architecture and internal registers that are capable of handling 8 parallel data signals. The three types of memory that can be utilized by the ATmega328 are Flash (32KB), SRAM (2KB), and EEPROM (1KB) [1].

This MCU is available in a DIP-28 package, meaning it has 28 pins. These pins include power and I/O pins. Many of the pins are multifunctional this allows the same pin to be used in different modes based on how the user configures it. This reduces the need for a larger pin count since the MCU does not need a separate pin for every function. This allows a user's design to be more flexible since the I/O pins can provide multiple types of functionality. More specifications for the ATmega 328 can be seen in table 10.

Clock Speed	16MHz
RAM	2KB
Storage	32 KB
Input Voltage	7-12V
Minimum Current	42 mA
Digital I/O Pins	14
PWM Pins	6

Table 10 ATmega328 Specifications

4.1.1.3 ATmega2560/Arduino Mega

The Arduino line offer a compelling alternative to the MSP430 Launchpad. Like the Arduino Uno, the Mega is similar to the MSP430G2 when it comes to price point and feature set. All of the features needed for the Funetics device are included with the Mega. Comparing the pure specifications of the Uno and the Mega aren't wildly different. The main hardware difference between the two is that the Mega includes more I/O pins, which could be utilized by more RFID sensors if needed.

The main difference between the Arduino Mega and the MSP430 are the libraries. The Arduino library is far more extensive compared to TI's libraries. And with the Arduino line of products being open source, there is far more reference material and design guides from the manufacturer, as well as a plethora of community designs available for reference.

Ultimately however, the ATmega2560 is not as widely used as its smaller brother, the Arduino Uno/ATmega328. And due to slight difference in libraries, these two factors result in a product that is more difficult to use. Further specifications can be seen in table 11.

Clock Speed	16MHz
RAM	8 KB
Storage	256 KB
Input Voltage	7-12 V
Minimum Current	40 mA
Digital I/O Pins	54
PWM Pins	14

Table 11 ATmega2560 Specifications

4.1.1.4 Raspberry Pi

The Raspberry Pi platform, similar to that of Arduino, is one loved by enthusiasts and professionals alike. The development boards are compact and offer a plethora of options for users. By leveraging an ARM chip, the Raspberry Pi is capable of supporting more complex software solutions. This includes even the ability to run full operating systems and accompanying software packages. The ARM processor is even able to output a video signal, but this feature and others are a bit overkill for the needs of the Funetics device.

Ultimately, unlike the ATmega chipsets, the ARM chipset is not open source. This is a problem when it comes to researching reference material for this project. There's also the factor of the typical use case of an ARM processor. While the pure specifications are comparable to the likes of the MSP430 and the ATmega line, the software library and capabilities are fairly different. The Raspberry Pi and more generally ARM processors are typically used more often when a full operating system is needed. Specifications for the ARM 11 can be seen in Table 12.

Processor	ARM 11
Clock Speed	700MHz
RAM	512 MB
Storage	via SD card
Input Voltage	5 V
Minimum Current	700 mA
Digital I/O Pins	8
PWM Pins	1

Table 12 ARM 11 Specifications

4.1.2 Peripherals

The Funetic board will need a microcontroller to have built in USB, serial ports, and multiple IO pins. Many common choices are going to be eliminated. Some peripherals can be handy to have: UARTs, SPI or I2C controllers, PWM controllers, and EEPROM data memory are good examples, even though similar functionality can frequently be implemented in software or external parts. It's beneficial if output pins can supply appropriate amounts of current for driving since LEDs are going to be used.

4.1.3 Microcontroller Final Selection

There were a few main factors that were taken in to account when choosing the MCU that led to our final selection of a microcontroller. These factors that were considered were the following aspects of the compared microcontrollers:

- Data Rate – Instructions per second and speed (in Hertz)
- Memory – Amount of RAM, EEPROM, and program memory
- Pin Outs – The number and type of pin outs available
- Size – The physical dimensions of the MCU
- Cost – The unit cost of the microcontroller and cost per MHz

The microcontroller that was decided upon was the ATmega328/Arduino UNO. As it is the MCU that has the most advantages of using and meets all of the technical requirements. It has AVR architecture. AVR architecture is known to be user friendly, powerful and inexpensive. Shown in Figure 11 is the block diagram for the ATmega328 architecture [1].

While the microcontroller will be used in the testing phase of this project we will be using the ATmega328 microprocessor to design the PCB for the prototype. The ATmega328 is the microprocessor that the Arduino Uno uses so this will simplify the amount of programming we will have to do. Once the ATmega328 microprocessor is programmed on the Arduino Uno for the first testing phase it can be removed from the Arduino UNO and placed on to the PCB for the final implementation of the prototype.

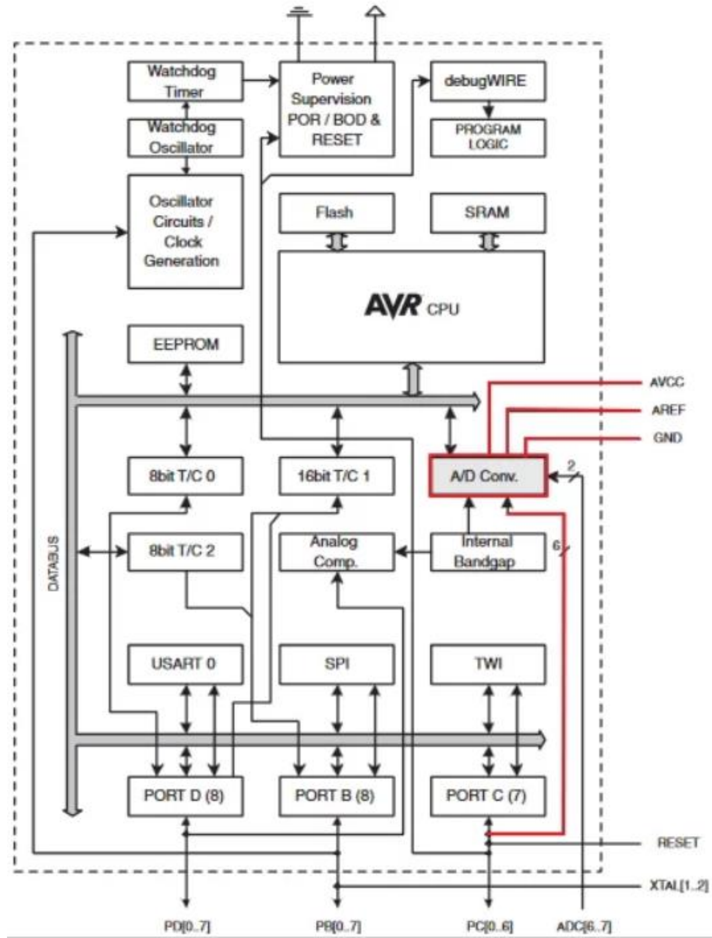


Figure 11 Block Diagram for the ATmega328 (Permission Pending)

4.2 LEDs

With the different types of LEDs available for purchase some research had to be done before choosing which LED the Funetic board would use in its design. The LED is important part of the design for the purpose of lighting up the acrylic balls that display the phonetics. There are many different types of LEDs to choose from on the market. LEDs have a PN junction that produces light when forward biased, packaged in a translucent plastic casing with metal connection points for the anode and cathode. One LED PN junction is capable of producing only one color of light. Figure 12 shows some of the size and shape differences of LEDs [31].

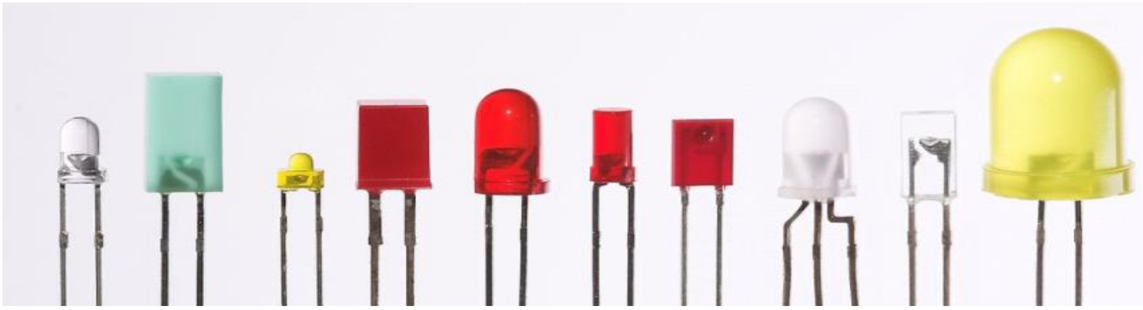


Figure 12 Different types of LEDs Reprinted with permission from Jameco Electronics

4.2.1 LED Comparisons

Since the design of the Funetic Board includes a light source to light up the phonetic balls the use of a LED will be a better choice over other light sources. This will allow for the use of different color lights and a compact but bright light source. The section will compare various LEDs that could be used in the Funetic Board. The LED selection will be an important selection since this will be what enhances the interactive aspect of the device.

4.2.1.1 Miniature LEDs

Miniature LEDs are single-die LEDs and come in sizes ranging from 2 mm to 8mm and have surface mount and through hole options. The typical current is in the range of from 1mA to 20mA [2]. Also the simplicity of this LED prevents them from being more than a single color. For the purpose of the Funetic Board the use of miniatures LEDs would not be efficient. As the board needs to have a large enough LEDs to brightly light up the acrylic balls.

4.2.1.2 High Power LEDs

High power LEDs also known as high output LEDs run on a much higher current range compared to the miniature LEDs typically ranging from 100s of mA to upwards of more than 1A. These high-power LEDs are often used in high powered flashlights and powerful LED lamps [2]. Also HP LEDs only seem be in white. This is not the outcome we want as the project design is for a variation in the visual lighting. The use of high power LEDs in the Funetic Board would not be efficient.

4.2.1.3 RGB LEDs

RGB LEDs stands for red blue and green LEDs they can produce a wide range of different hues by using the combination of the colors. Although not all colors are producible with the RGB LEDs such as the colors brown and pink are two of the color schemes that are hard to achieve [2]. RGB LEDs could be a good idea to choose for the project as they offer a large variation of colors given the appropriate voltage levels running through the device. Their size of 5mm fits in with size specification of the project.

Another consideration to take into thought for the RGB LEDs is that they can come in different shapes the most common are the square and oval shapes. Both the square and oval shape design lack the same amount of light from the bottom as from the top of the LED. This should not be a problem for our design since the top of the LED will be placed under the object that is intended to light up.

4.2.1.4 Flashing LEDs

Flashing LEDs are just like normal LEDs but have an Integrated Circuit (IC) contained within them along with the LED itself. Usually flashing LEDs run at a low frequency, so to produce 3 flashes per second it would have a frequency of 3Hz [2]. This type of LED is not useful for use in the Funetic Board the LEDs used will be to have a regular output. It could be possible to use this type of LED, but the task would be much more intricate to use it for the purpose that we need.

4.2.1.5 Strip LEDs

Strip LEDs can come in a few different options single color, multicolor, or RGB. They also come in different sizes and shapes. More recently this type of LED has become more popular for purchasing [2]. This product would not be good to use for the purpose of the Funetic board. The reason for this would be due to two things, one reason is that the spacing required for the Funetic board LEDs does not line up with the spacing on the researched strips. Another reason would be that with amstrip LED it could interfere with some of the other aspect of the project design such as the sensors.

4.2.2 LED Decision

The chosen LED for the Funetic Board is going to be the RGB LEDs. Since they are able to produce a wide range of colors. RGB LEDs are desirable to the project over single-color LEDs since we want the colors to change with different sequences of ball placements. They are also powerful enough to display the amount of brightness we need to light up the acrylic balls**.**

4.2.3 Calculating the LED Resistor Value

A resistor is needed in series with a LED to limit the current that travels through the LED. So, the current does not cause the LED to burnout. The formula used to calculate the Resistor value is $R = \frac{V_s - V_l}{I}$ where R is the resistor value, V_s is the voltage of the source, V_l is the voltage for the LED, and I is the current for the LED. This is shown below in figure 13 [32].

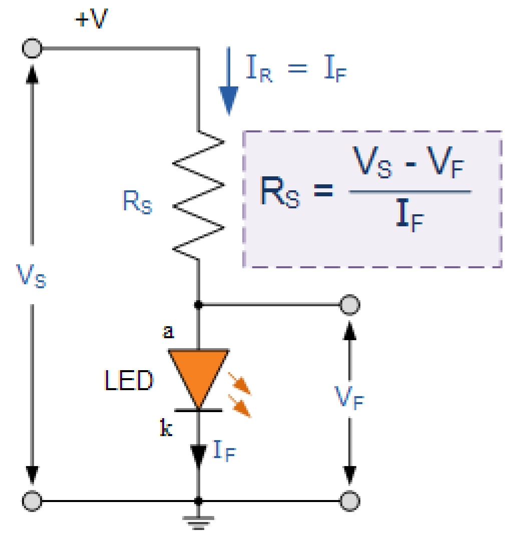


Figure 13 Circuit schematic for calculating a Resistor for a LED (Permission Pending)

Connecting LEDs in series

In the Funetic Board a series of LEDs will be used to light up the acrylic balls this is beneficial since when LEDs are connected in series the same amount of current can flow through them. The only difference is considering the voltage needed for each LED so V_{LED} would then been the sum of all the individual LED voltages. This process can be seen in figure 14 [32].

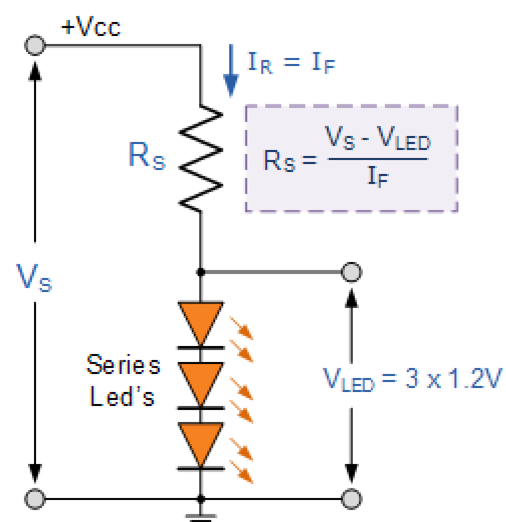


Figure 14 Showing how to calculated a resistor value for LEDs in Series (Permission Pending)

4.3 Batteries

Funetics will require a power source in order for the system to operate, whether it's drawing from an output for power or the use of batteries. Since portability is an important aspect to the system, we would prefer using batteries to power the system. There are a handful of pros and cons between the uses of different battery types. Figure 15 shows energy densities between different battery types and listed below are some of the choices we will consider [33]:

- Nickel Cadmium
- Nickel Metal Hyrdride
- Lithium Ion
- Lithium Ion Polymer
- Lead Acid
- Alkaline

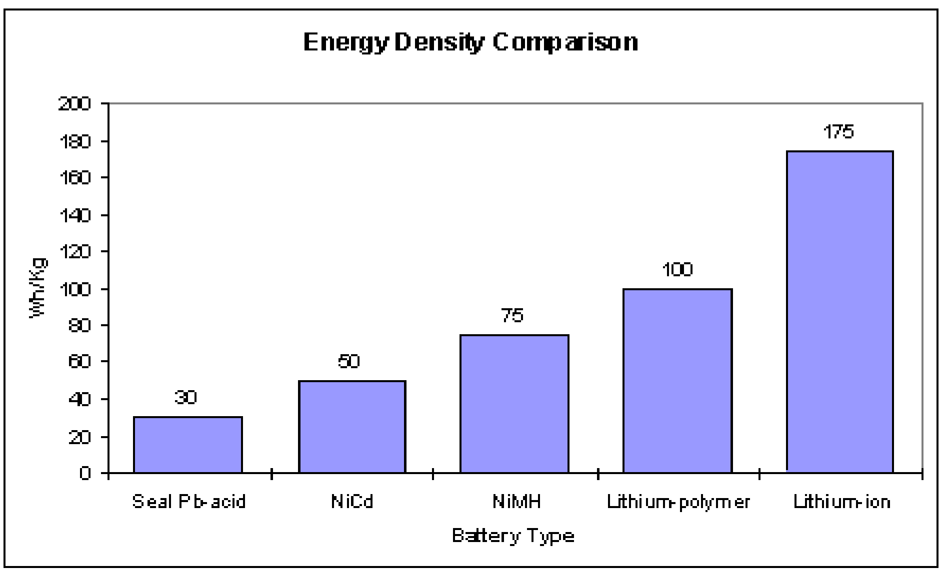


Figure 15 Energy densities between different battery types (Permission Pending)

4.3.1 Nickel Cadmium

The first, Nickel Cadmium (NiCd) is used where long life, high discharge rate and economical price are important. It prefers fast charge to slow charge and a pulse charge to DC charge. A unique perk to this type is that it is the only battery type that operates well under intense working conditions. It becomes a problem if you do not use it to its full potential occasionally. When left alone for too long or for short uses, large crystals will form on the cell plates and will decline in performance. It seems to be commonly used in bidirectional radios, biomedical devices, and high-end video cameras though it has a low energy density.

Unfortunately, it contains toxic metals and proves to not be very environmentally friendly.

4.3.2 Nickel Metal Hydride

Nickel Metal Hydride (NiMH) has a much higher energy density compared to other types. In comparison to the previous, Nickel Cadmium, there are nearly a 40 percent increase in energy density. It can be pushed even higher but until further studies, the negative side effects may outweigh the positive benefits. Nickel metal hydride has been more and more replacing the nickel cadmium in markets. Cycling under heavy load and being stored at high temperatures can easily reduce the life expectancy in addition to making it less durable. The fact it also suffers from high self-discharge could be another cause for it to run out quicker and have a reduced life time. It contains no toxic metals though and more useful towards cell phones and non-desktop type of computers or tablets. Figure 16 shows Charge state for NiCd and NiMH [34].

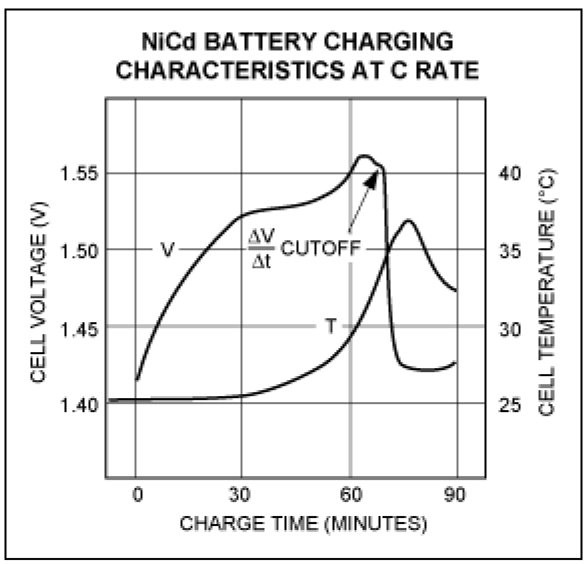


Figure 16 Charge state for nicd/nimh (Permission Pending)

4.3.3 Lithium Ion

Lithium Ion (Li-ion) dominants as the fastest growing battery system Li-ion is commonly used in applications that desire high-energy density and put lightweight as a top priority. Lithium is the lightest of all metals, has the greatest electrochemical potential and provides the largest energy density per weight. These qualities are the reasons it makes it a top notch when looking for the best lightweight battery. The energy density is twice that of the normal NiCd and with the possible increasingly potential to become three times that of it. Furthermore, it behaves similarly to the NiCd in the sense of load characteristics. The flat discharge presents effective utilization of the stored power in a useful voltage spectrum. The high cell voltage makes it so battery packs can be only one cell which is popular since most devices run on a single cell and allows creation of simplified battery designs.

Additionally, it is a low maintenance battery that most other batteries cannot state. Compared to the NiCd, the self-discharge is less than half of it. There is no memory nor scheduling necessary to extend the battery's life. On the contrary due to its fragileness, a protection circuit is a necessity to assure everything is secured. This can cause limitations to its peak voltages and currents. One concern that is tried to keep quiet is that the aging process of lithium ion batteries deteriorates at a noticeable level quite rapidly and may find it to frequently fail. Shown in figure 17 is the charge state for Lithium Ion [33].

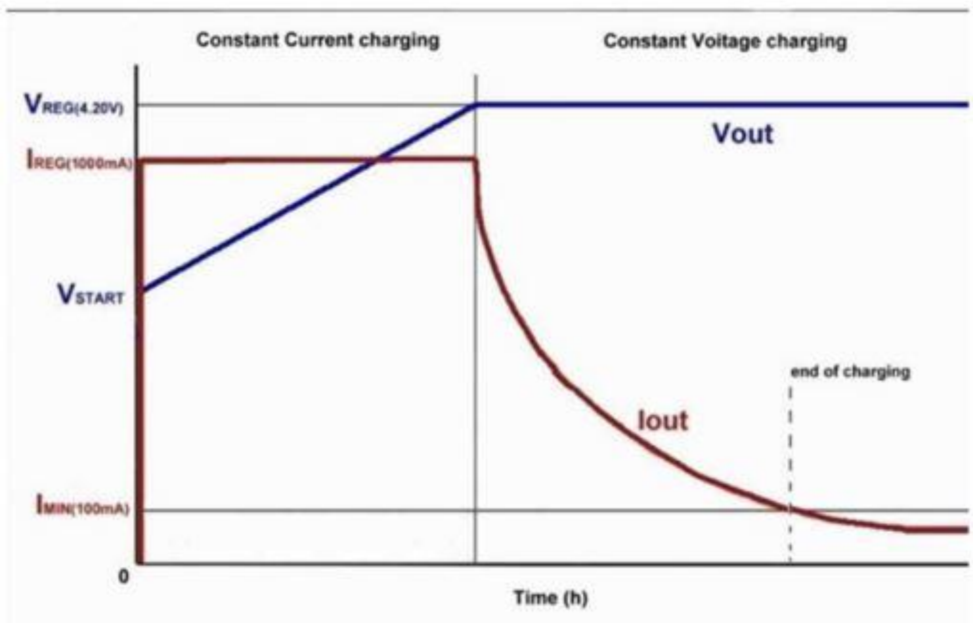


Figure 17 Charge state for lithium ion (Permission Pending)

4.3.4 Lithium Ion Polymer

Lithium Ion Polymer (Li-on polymer) provides the same characteristics of the Lithium Ion in terms of the super skinny shape and simplified packaging. The original design for lithium polymer though used a dry solid polymer electrolyte. It didn't allow the conduction of electricity but instead an exchange of ions. The dry design provided simplifications in respect to fabrication, safety, and slim-like geometry measuring as thin as one millimeter. Without the use of liquid or gelled electrolyte, there was no danger of flammability. Due to the poor conductivity, the internal resistance is too high and cannot deliver the current burst required for modern day communication devices. To make a small lithium polymer battery more conductive, some gelled electrolyte was added to counteract the disadvantage. In essence, most lithium polymer batteries today are a hybrid and contain the gelled electrolyte which make the lithium ion polymer. The main difference between the lithium ion and lithium ion polymer is that the lithium ion polymer is unique to the replacement of porous separator. Uses are also similar to that of Nickel Metal Hydride and Lithium Ion, mainly cell phones.

4.3.5 Lead Acid

Lead Acid is the most economical when using applications requiring larger power and weight is not a priority. Lead acid batteries have been broken up to two types. One being the smaller sealed lead acid and the other larger valve regulated lead acid. Though, both batteries technically are the same. The sealed lead acid type is designed with a low over-voltage potential to not allow the battery from reaching its gas-generating potential during charge. Resulting in these batteries to never be charged to their full potential as overcharging could cause water and gassing depletion. Lead acid is not subject to memory and leaving the battery on float charge for extended periods of time would not cause damage. It has one of the best charge retention among rechargeable batteries.

In contrast, the NiCd loses roughly 40 percent of its stored charge in just three months. The sealed lead acid would lose the same amount but in the duration of a full year. It is relatively cheap to buy but maintenance can easily reap that benefit. Also, it must always be stored in a charged state and takes quite a lengthy time to charge. Unlike the NiCd, not using it completely is the way it should be treated. Full discharge causes problems and wear-down like sulfation. Sealed lead acid provides 200 to 300 discharge/charge cycles. The life expectancy is quite short compared to others and most likely due to the grid corrosion of the positive electrode, expansion of the positive plates, and depletion of the active material. Unlike the lithium family, the lead acid battery has the lowest energy density. Making it undesirable for require smaller size. It isn't having harmful as the NiCd but it still is considered unfriendly to the environment. Primary uses include emergency lights, hospital equipment, handicap devices and motor vehicles. Shown in figure 18 has comparison between life times of Alkaline NiMH and NiCd [33].

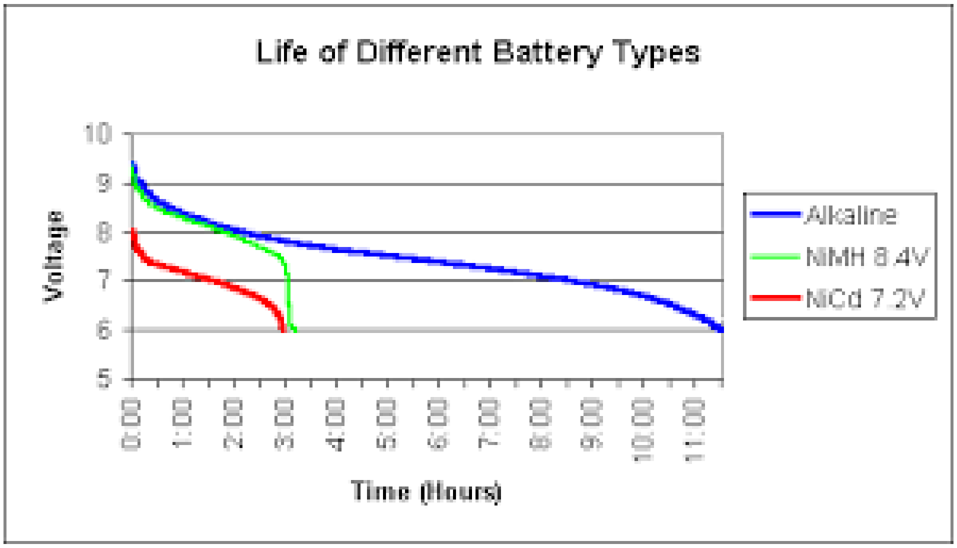


Figure 18 comparison between life times (Permission Pending)

4.3.6 Alkaline

Alkaline batteries are the only one here that is non-rechargeable but was worthy to consider due to popularity, commonly used and easily available. These batteries have decent capacity, but you will rarely find that kind of information posted on the packaging. Despite the lack, after much testing it was observed the spread of max capacity only varied by 9-15%. Compared to some of the others above, storage can be a big problem. Alkaline batteries have incredible shelf life, up to 8 years. NiMH's lose nearly 20% of their capacity by the first month. On the other hand, they don't work well in high draining devices like digital cameras. They are not optimal when it comes to powering something requiring a lot of juice and the voltage drops significantly more linearly than the less discharging NiMH or NiCd. It won't have as long of a run time, but the initial voltage starts higher than that of those and provides a bit more power straight off the bat but will decrease quicker.

Leaking is a big problem for alkalines. They leak more commonly than any other kind of battery. Another problem, they are harder to reuse and recycle than rechargeable batteries. They aren't as environmentally unfriendly as the NiCd's but they are hard to strip all the useful metals out of it and makes it not very cost-effective to recycle. Figure 19 compares the characteristics of the six most commonly used rechargeable battery systems in terms of energy density, cycle life, exercise requirements and cost [33]. The figures are based on average ratings of commercially available batteries at the time of publication and could be easily changed as modern improvements occur.

	NiCd	NiMH	Lead Acid	Li-ion	Li-ion polymer	Reusable Alkaline
Gravimetric Energy Density (Wh/kg)	45-80	60-120	30-50	110-160	100-130	80 (initial)
Internal Resistance (includes peripheral circuits) in mΩ	100 to 200[1] 6V pack	200 to 300[1] 6V pack	<100[1] 12V pack	150 to 250[1] 7.2V pack	200 to 300[1] 7.2V pack	200 to 2000[1] 6V pack
Cycle Life (to 80% of initial capacity)	1500[2]	300 to 500[2,3]	200 to 300[2]	500 to 1000[3]	300 to 500	50[3] (to 50%)
Fast Charge Time	1h typical	2-4h	8-16h	2-4h	2-4h	2-3h
Overcharge Tolerance	moderate	low	high	very low	low	moderate
Self-discharge / Month (room temperature)	20%[4]	30%[4]	5%	10%[5]	~10%[5]	0.3%
Cell Voltage (nominal)	1.25V[6]	1.25V[6]	2V	3.6V	3.6V	1.5V
Load Current - peak - best result	20C 1C	5C 0.5C or lower	5C[7] 0.2C	>2C 1C or lower	>2C 1C or lower	0.5C 0.2C or lower
Operating Temperature (discharge only)	-40 to 60°C	-20 to 60°C	-20 to 60°C	-20 to 60°C	0 to 60°C	0 to 65°C
Maintenance Requirement	30 to 60 days	60 to 90 days	3 to 6 months[9]	not req.	not req.	not req.
Typical Battery Cost (US$, reference only)	$50 (7.2V)	$60 (7.2V)	$25 (6V)	$100 (7.2V)	$100 (7.2V)	$5 (9V)
Cost per Cycle (US$)[11]	$0.04	$0.12	$0.10	$0.14	$0.29	$0.10-0.50
Commercial use since	1950	1990	1970 (sealed lead acid)	1991	1999	1992

Figure 19 Chart Comparison for battery Specifications Reprinted with permission from BatteryUniversity.com

4.3.7 Battery Final Selection

After thoroughly examining different battery types, it can be concluded that the most practical one to use would be a lithium ion battery. It fits our requirement of something that is lightweight, environmentally friendly, doesn't need to be used to full depletion, has minimal maintenance, and has a long enough life expectancy for the desired lifetime of the device.

4.4 SD Cards

Secure Digital (SD) cards may be required in some devices like cameras, phones, or tablets to be used for primary storage or just to increase storage capacity. However, different devices require different types of SD cards and not all SD cards are created equal. They came in different speed classes, capacities, and physical sizes.

4.4.1 SD Card Comparison

There are currently four standard different speed classes that include 2, 4, 6, and 10 then a special class 1 and 3 for Ultra-High Speeds (UHS) that devices are designed specifically for. Class 2 is the slowest, which is commonly found in standard video recording devices. Class 10 is the fastest and is used for high definition devices or things requiring constant high processing. The speed specs for each card type is not limited to that standard as it is the minimum speed and can exceed higher rates. The minimum speeds for the special classes, Ultra-High Speed, begin at 10MB/s for class 1 and reach a higher minimum of 30MB/s upon reaching class 3.

As technology gets better, the size of memory is able to get smaller due to Moore's law. About roughly every 18 months, the number of transistors per square inch on integrated circuits will double. In result, the size of the equivalent memory capacity is able to fit on a smaller physical size which formed the miniSD then the microSD. Compared to the standard size SD card, the microSD card is less than half the size of it for the same about of memory. Shown in figure 20 is the different types of SD cards to choose from [35].

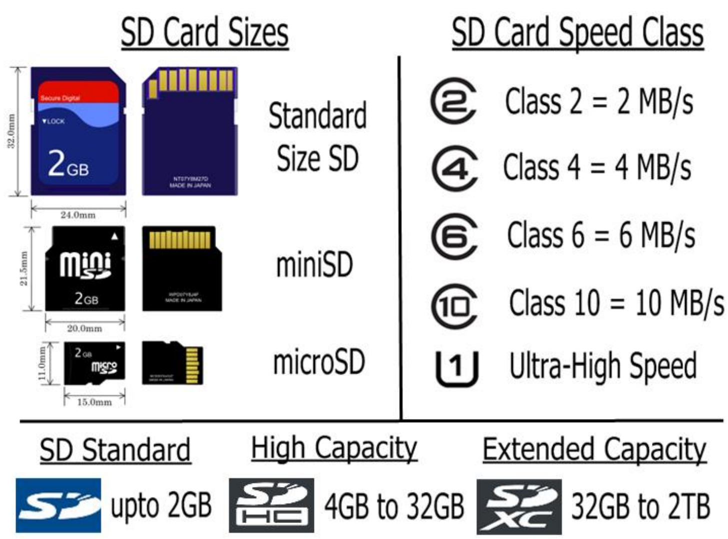


Figure 20 SD card types (Permission Pending)

4.4.2 SD Card Selection

For Funetics, it would be most optimal to use a smaller SD Card size with a decent capacity to allow the extension of adding more words and phonetics to the database while have not a high priority towards the speed class.

4.5 Wireless Technology

For Funetics to function the way intended it requires a wireless communication system. This section will discuss the types of communication technologies the team considered, how these technologies operate, the positive and negative aspects of each given what our intended use is, and ultimately which technology was chosen. Details on how our chosen wireless communication technology works will be helpful to the Funetics team once we begin the hardware integration.

4.5.1 Why Use Wireless Communications?

In order for Funetics to have a simplified interaction model for the intended target audience it makes the most sense to implement a wireless communication system to have the device work the way we want it to. The Funetics team wants children to be able to easily use the device; to simply identify which phonemes a word requires and to place it on the device. Therefore, there needs to be some form of wireless communication between the physical representation of the phonemes, small balls, and the device itself that the balls are placed on.

If a wireless communication system was not utilized for Funetics then the phonemes would need to be physically represented on the device in some way. This would likely be done with some sort of button or switch system. However, there are 44 phonemes in the English language. Even if the Funetics device was limited to words no larger than five letters and/or phonemes it would call for a very large and unwieldy device.

4.5.2 Bluetooth

Bluetooth is a form of wireless communication that is primarily used to send data over short distances. It utilizes ultra-high frequency, short wavelength radio waves that typically operate from 2.4GHz to 2.485GHz in the ISM band. Data is divided and transmitted via packets, with the packets being transmitted on one of the 79 different Bluetooth channels. These channels have a bandwidth of 1MHz. The packets are transmitted in a master-slave communication model. Older revisions of the technology can utilize up to seven slaves capable of receiving communications from one master, which is desirable for Funetics. More recent versions of Bluetooth are capable of connecting up to 10 devices at a time.

One feature that makes Bluetooth so popular is its low operational power. From the release of Bluetooth 4.0 and subsequent versions the power efficiency dramatically improved. It is alternatively known as Bluetooth Low Energy, or BLE for short, and was created with devices that are able to run off of a watch, or button cell, battery in mind. These are relatively small batteries with low operating voltages, most of which around 1.5V. Bluetooth LE devices are meant to operate for months, or even years, on a single battery. There are two types of implementation available for BLE, the first of which is single-mode implementation, and the second is dual-mode implementation. With single-mode implementation these devices only carry the Bluetooth LE protocol stack. And the dual-mode implementation takes an existing "Classic" Bluetooth controller and integrates the newer Low Energy functionality to it. This implementation retains all of the features of a fully powered Bluetooth radio, but is also able to go into a low power state and act as a BLE device.

For the purposes of Funetics it would be nice to have the Bluetooth LE functionality. The project doesn't have the need for transferring large amounts of data or working over larger distances that the Classic Bluetooth radios are capable of doing. That being said it's not the belief that the device will be hard pressed for saving energy, so it's not believed that the power saving element of BLE radios compared to Classic radios would be a significant gain. There's also the worry of pairing Bluetooth transmitters with a receiver. Most Bluetooth devices during the pairing process require some sort of user interaction to confirm the pairing of devices. Due to Bluetooth ability to transmit information the lack of a user prompt for connection is a security concern for most uses of the standard. There are some simple pairing implementations, namely using the "just works" authentication mechanic, that don't require any user input for Bluetooth devices to connect [3].

4.5.3 NFC

Near-Field Communication, a subset of RFID, is a short range wireless communication technology. NFC interactions always take place between an interrogator and a target. This typically involves an active NFC device generating radio waves to power a passive element. An active NFC implementation means that it contains its own power source to generate its own radio waves. Passive NFC elements don't have their own power sources an instead require radio waves from an interrogating NFC device to power its antenna through induction. These passive NFC elements can therefore take very simple forms, such as small plastic tags, or even stickers. This is shown in Figure 21.

NFC primarily operates on the 13.56Mhz ISM band within a distance of 10 cm. Similar to RFID, NFC systems can incorporate passive and/or active components. A passive target device must first be interrogated by another device. Once powered by the radio waves, it will then modulate the interrogating radio waves to transfer information. For NFC to work it utilizes electromagnetic wave induction via looped antennas. These antennas, when in range of another NFC antenna, will activate and begin the process of exchanging information. It operates on the unlicensed ISM radio frequency band ISO/IEC 18000-3 standard (including the ISO/IEC 14443, ISO/IEC 18092, and FeliCa standards) on the 13.56MHz frequency band.

Devices equipped with an NFC radio are capable of operating in three different modes. NFC card emulation allows NFC devices to act as a “smart card” (a generic term used to describe any type of debit/credit card with integrated circuitry) to be utilized in contactless payment or ticketing transactions. NFC reader/writer is one potential avenue for Funetics’ wireless communication solution. This allow NFC devices to read the information stored in very cheap NFC tags that usually come in the form of labels/stickers. NFC peer to peer allow for two NFC active devices to communicate and transfer information between each other.

Figure 21 Example NFC Sticker (with Nokia branding) Permission Pending

NFC tags typically store data passively and can only be read, however there are some tags that can be written to by an NFC device. The usual amount of data storage in tags ranges from 96 bytes to 8192 bytes. This range would be adequate for the needs of Funetics. Tags are capable of storing secured personal information, such as credit card information or contact information, but such a feature isn’t necessary for this project [4].

4.5.4 RFID

Radio-frequency Identification utilizes electromagnetic waves to identify objects that are RFID tagged. These tags act as identifiers for the object with the tag. They can be implemented in different ways and can be utilized in a variety of applications including, but not limited to, animal identification, inventory management, payment systems, secure building access, product tracking, hospital patient tracking, and transportation tracking.

Some implementations of RFID are active, meaning they have a power source to generate their own radio waves and possibly increase the range of said waves if needed. The power source is typically some sort of battery power. With a more accessible power source, active RFID implementations are able to transmit their data periodically. That being said, RFID data transfer in general only happens when data is required for processing something specific. Therefore, periodic data transmissions of active RFID systems are limited. Active RFID systems are still more reliable than passive systems thanks to that dedicated power source. Due to this dedicated power source and increase reliability, active RFID systems can have a range in the low hundreds of feet. It's possible for active RFID systems to also have larger storage capacities when compared to passive RFID.

There are some undesirable aspects of active RFID, which includes the weight of the tags. Due to the inclusion of a dedicated power source like a battery, this adds a significant amount of weight to the tag. An additional downside to active RFID solutions is the cost. When compared to the price of passive RFID systems, active ones tend to cost significantly more money

Other implementations are passive, so they rely on energy collected from the interrogating, or reader, radio waves of nearby RFID readers in order to send information. That being said, some passive implementations could have their own power source, but only activate when prompted by an RFID reader. The range of passive systems are far less than active ones, typically no more than 20 feet. This is due to a lack of a dedicated power supply. Passive tags typically don't store much information either. Usually the information is basic use for identification purposes.

The range of passive tags, lack of a power supply, and the small amount of storage space are tradeoffs to be considered for the upsides of passive RFID tag systems. Passive tags are very low cost. The lack of a built-in power supply, the small amount of storage, and the simple fact that passive tags are sometimes meant to be disposable make for low manufacturing costs, which results in a low price point for buyers. Shown in Figure 22 is a passive tag.

Figure 22 RFID Tag

If a tag is read only then the serial number is set when it is manufactured, and said serial number can be put into a database. These types of tags are less costly due to this. If a tag is read/write, then the tag can have an identification written to it by the user, or potentially by an RFID reader that is interrogating a read/write tag. There are also write once, read many tags, aka WORM tags, that allow users to write information one time to be stored, and from there on out can only be read. Non-volatile memory is used to store the tag identification information.

An RFID system can be classified in several different ways. An Active Reader Active Tag (ARAT) system includes active tags which are interrogated by an active reader. An Active Reader Passive Tag (ARPT) system includes passive tags that are activated by the interrogating waves of the active reader. A Passive Reader Active Tag (PRAT) system has a passive reader that is only able to receive signals from active tags. For our purposes an ARPT system would be best.

RFID systems are able to operate on a variety of frequency spectrums. The unregulated low frequency spectrum operates between 120kHz and 150kHz with a range of 10 cm. The high frequency spectrum operates at 13.56MHz with a range of 10 cm to 1 meter. This is an ISM (industrial, scientific, and medical) radio band and is regulated by the ITU Radio Regulations. There are two ultra-high frequency bands. The first is 433MHz for specialized short-range devices at 1 to 100 meters. Then there is another ISM band at 902 to 928MHz in North America for a range of 1 to 12 meters. There are two microwave bands, the first being an ISM band from 2450MHz to 5800Mhz with a range of 1 to 2 meters. This is typically used for 802.11 Wi-Fi and Bluetooth. The second microwave band of 3.1 to 10 GHz is of no concern to us. For our purposes, the ISM 13.56Mhz band would be of most use.

4.5.5 Wireless Communication Technology Decision

Based on the feature sets of these technologies, it was decided that RFID would be the best for the goals of this project. The quick and simple identification system that is provided by RFID is exactly what is needed. An active reader, passive tag system is all that would be needed out of a wireless communication technology.

RFID seems to offer the best solution for this at the ranges that are needed. The key specifications of interest can be seen in table 13.

	RFID	NFC	Bluetooth
Range	20 ft	10 cm	10 m
Frequencies	120kHz – 150kHZ, 13.56MHz, 433MHz, 902 – 928MHz, 2450MHz – 5800MHz	13.56MHz	2.4GHz
Frequency Standards	Unregulated low frequency, ISM bands including ISO/IEC and FeliCa	ISO/IEC 14443, ISO/IEC 18092, FeliCa	ISM band
Passive Tag Implementations	Yes	Yes	No

Table 13 Key Specification Comparisons

4.6 Wireless Sensor Comparisons

This subsection details various RFID sensors that were of interest to the project team for use as our wireless communication reader. A good quality and reliable RFID module is necessary for use in the Funetic device so that the team can ensure the optimal chance for the device to be successful.

4.6.1 MFRC522

The RFID sensor MFRC522 is manufactured by NXP Semiconductors and is distributed by several different companies. The 522 can be utilized for wireless communications on the standard 13.56MHz spectrum and the reader supports the ISO/IEC 14443 A/MIFARE and NTAG standards. It's able to interface over Serial Peripheral Interface (SPI), Serial UART, and I2C. It has a typical operation distance of up to 5 cm. This sensor is shown in Figure 23.

Figure 23 Sensor MFRC5222

The 522 has two different manufacturing versions, the MFRC52201HN1 which is better known as version 1.0, and the MFRC52202HN1 which is better known as version 2.0. Among the improvements in version 2.0 include an increased stability of the IC reader when in rough conditions, an additional time prescaler, and a corrected CRC handling for when the RX Multiple is set to 1.

Additional hardware specifications include a programmable timer, an internal self-test, and a power supply voltage operation range of 2.5V to 3.3V [5]. Table 14 list additional specifications.

Voltage	3.3V
Current	6.5mA
Interface Support	SPI, I2C, UART
Frequency	13.56MHz
Range	5 - 10 cm
Standards Support	ISO/IEC 14443 A/MIFARE, NTAG
Average Cost	$5/unit (low volume)

Table 14 MFRC 5222 Specifications

4.6.2 PN532

The PN532 is an NFC sensor manufactured by NXP Semiconductors and is distributed by several different companies. The chipset operates on the standard 13.56MHz frequency spectrum and also supports as many as 6 operating modes; ISO/IEC 18092, ISO/IEC 14443A/MIFARE Reader/Writer, ISO/IEC 14443B

Reader/Writer, FeliCa Reader/Writer and FeliCa Card emulation, and MIFARE Classic 1K or 4K card emulation.The PN532 supports all three-major interface controlling mechanisms with SPI, I2C, and UART. Other specifications of note include a ROM of 40 KB, RAM of 1 KB, typical operating distance of up to 5 cm for ISO/IEC 14443A, ISO/IEC 14443B, FeliCa, or NFCIP-1 modes, a typical operating distance of up to 10 cm while in ISO/IEC 14443A/MIFARE or FeliCa card emulation modes, programmable timers, and a power supply voltage operating range of 2.7V to 5.5V. Table 15 lists the technical specifications [6].

Voltage	2.7 - 5.5V
Current	25mA
Interface Support	SPI, I2C, UART
Frequency	13.56MHz
Range	5 - 10 cm
Standards Support	ISO/IEC 18092, ISO/IEC 14443A/MIFARE Reader/Writer, ISO/IEC 14443B Reader/Writer, FeliCa Reader/Writer emulation, FeliCa Card emulation, MIFARE Classic 1K or 4K card emulation
Average Cost	$20/unit (low volume)

Table 15 PN532 Specifications

4.6.3 Parallax RFID Reader

The Parallax RFID reader is made by Parallax in conjunction with Grand Idea Studio. This RFID reader operates within the unregulated frequency spectrum at 125kHz. It comes in both a Serial interface version for connecting to microcontrollers and a USB interface version for connecting to computers. We would be interested in the former, which has the model number of #28140.

The Parallax RFID reader only works with EM Microelectronics (EM4100) passive read only tags, which Parallax also produces. The Serial version requires a 5V power supply input, with a possible maximum operational range of 4.5V to 5.5V. The SOut pin operates at 2400 bps, with 8 data bits at a time, no parity, and 1 stop bit. The antenna built into the Parallax RFID reader is meant to operate within a range of 4 inches [7]. Shown in Table 16 are the specifications.

Voltage	4.5 - 5.5V
Current	100mA
Interface Support	SPI, I2C, UART
Frequency	125kHz
Range	10 cm
Standards Support	n/a
Average Cost	$50/unit (low volume)

Table 16 Parallax RFID Specifications

4.6.4 RDM6300

The RDM6300 is is an RFID module meant to work on the 125kHz unregulated frequency spectrum. It has support for an external antenna, has an effective operating distance of up to 150 mm, operates over the UART communication standard, can decode incoming signals in less than 100 ms, and includes support for EM4100 compatible RFID tags [8]. Table 13 list more of the RDM6300 specifications.

Voltage	5V
Current	< 50 mA
Interface Support	SPI, I2C, UART
Frequency	125kHz
Range	> 5 cm
Standards Support	n/a
Average Cost	$7.50/unit (low volume)

Table 17 RDM 6300 Specifications

4.6.5 Reader Decision

As previously mentioned, the best wireless communication technology to utilize in Funetics is RFID. It offers a feature set that is appealing to the needs of the project. The MFRC522 was selected as the RFID reader of choice due to its low cost, low power requirements relative to other solutions, an operating range (10 cm) that works well for the project's needs, as well as a relatively easy integration process with the Arduino UNO microcontroller that will be utilized by the Funetics device. Block diagram showing integration is shown in figure 24 [36].

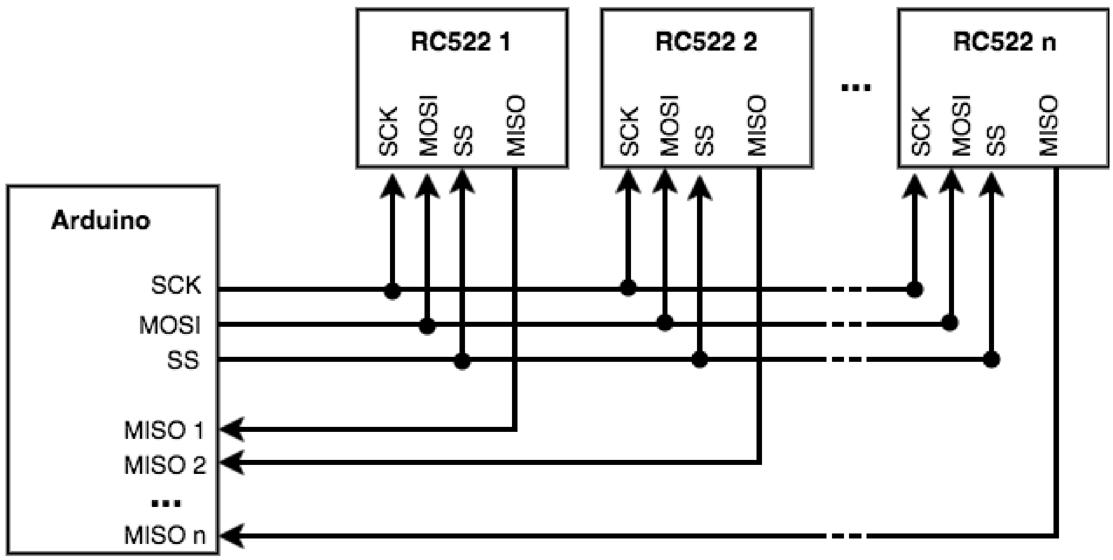


Figure 24 Integration for the RFID sensors and Arduino Uno Reprinted with permission from ArduinoStackExchange.com

4.7 Housing

The Funetic Board housing is a completely new and unique design. The housing is an extremely important aspect of our design because it is the user interface that ties all of the concepts we are trying to teach together. The housing will be kid friendly and easy to use for everyone. The next sections will outline the different components of our Funetic Board housing: spheres, main housing material, manufacturing process, and dimensions.

4.7.1 Spheres

The spheres are the most important aspect to our design because they are the liaison between the user and our technology. Theoretically, the spheres are the only object that the user has to touch to use the board correctly. Since the spheres are going to be touched, placed, and possibly even dropped, they have to be extremely durable and functional. Glass, polystyrene styrofoam and acrylic are all materials considered for our spheres. Although glass would have a beautiful aesthetic, it would be too heavy and fragile for Funetic Board. Acrylic is a clear thermoplastic material that is a lightweight and durable substitute for glass. The impact strength of acrylic is higher than both glass and polystyrene making it an ideal material for our application. Sphere durability is not our only standard for material choice, light emission must be considered as well. Each sphere is going to be placed on an LED, with the LED color brightly encompassing the ball. Polystyrene styrofoam would not have the light emission needed for such an effect. Acrylic has a refractive index and it can transmit up to 92% of visible light, making it perfect for out design.

After choosing acrylic for our sphere material, we needed to decide how we were going to display the phenomes onto the surface of the ball. There are many different options to consider, but since these balls will be constantly touched and tampered with, durability is essential. Some of the first ideas that came to mind were to use a permanent marker to display the letters, hot gluing paper to surface of ball, or using acrylic paint. Using a permanent marker would be the quickest and cheapest way to execute this design. We decided upon using the marker technique and since it was our first choice, we tested it to see if it met our specific requirements. We used an acrylic container and wrote our phenome symbols onto the surface with the thick sharpie. The result was not what we had originally intended. The marker would wipe itself off while trying to thicken the letters. Also after touching the ball repeatedly over a few days, the marker would fade and wash off.

Since the execution of the marker didn't work the way we intended, we decided that the best choices for our design would be either hand painted symbols or vinyl die cut letters. Hand painted symbols would be taking a more artistic approach and they may not be as readable as vinyl die cuts. After researching acrylic paints, the paint is not durable enough to withstand constant touching and tampering. Painting the entire sphere with a primer overtop the letter increases durability, but also changes the texture of the ball and with use overtime, would still not be durable enough. The hand painted letters may also not be as legible compared to die cut letters. Another downside to using acrylic paint would be the time commitment it would take to hand paint each complex phenome symbol on 15 different spheres. Funetic Board also could be expanded to have even more balls and phenome options. Thus, painting each ball is both imperfect and unrealistic for both our current and future executions.

After both the permanent maker and the acrylic paint ideas showed to be nonviable, it turns out that the vinyl die cut option is the best choice for our application. With this technique, the phenome symbols can be created in a software where font, size, and color can all be customized. The symbols will then be cut onto vinyl material with a die cut machine. The vinyl die cuts can be applied with heat to the surface, leaving a crisp, clean, and easy to read symbol on our phonetic spheres.

4.7.2 Main Housing Material

In order to choose a material for the Funetic Board housing, there a few considerations to take into account. We need a material that meets our performance requirements, is easy to produce, and has the right aesthetic properties. The materials taken into consideration for Funetic Board are plastic, wood, and aluminum. The Funetic Board is geared for children, so a material needs to be kid friendly, as well as durable. Plastic was the first option because it is highly accessible and affordable, but when it comes to machining plastic does not seem like the right choice. Not only is plastic hard to machine, securing our circuit boards into the material would be cumbersome since plastic requires additional hardware when mounting other objects. Our main considerations for this housing came down to wood and aluminum.

Since durability is so important to Funetic Board, aluminum would be the first choice. Unfortunately, it has too many drawbacks for our specific application. Aluminum is much more expensive than wood, both in raw material and in its machining process. Also, Funetic Board is geared for children in a fun learning environment and aluminum would make the device look too industrial and less appealing. Thus, we chose wood for its durability, easiness to machine and aesthetic value.

4.7.3 Manufacturing Process

When it comes to manufacturing our project housing, there are three reasonable machining methods. The first method to consider is using a CNC milling machine to manufacture our design. CNC mills are computer controlled machines that use sharp tools to remove material in the way desired. They are capable of machining a large variety of different materials, ranging from metal, wood, acrylic and even modeling foams. CNC milling is a very common and versatile choice when it comes to choosing a machining process. Although CNC milling is a popular choice, it has some drawbacks. Some downsides that come with the CNC milling process are geometry restrictions and part complexity limitations.

The second machining option to be considered is 3D printing. Instead of using a subtractive method like CNC milling, 3D printing uses an additive method in machining. 3D printing is a relatively new process to manufacturing and it's becoming more and more popular. Unlike CNC mills, 3D printers can print designs with non-natural geometries and part complexities. On the other hand, 3D printers do not have the versatility in materials that the CNC mills have. 3D printers are normally restricted to a small selection of materials such as resins or thermoplastics. These materials are not as robust as the materials that are used in CNC milling, and although you can mix woods and metals into the plastics, it is not the same as using a solid piece of material such as wood. 3D printing shines when it comes to exotic applications and small prototypes that can be made with plastic. Overall, 3D printing and CNC milling are both viable processes for the Funetic board.

Our last consideration when it comes to manufacturing Funetic Board, is a CNC router. A CNC router is very similar to a CNC mill except a mill moves in an x/y coordinate and the spindle moves in the z coordinate, while a router's spindle moves in x/y/z coordinates. CNC routers are normally on a set table and move the material being machined, while mills are stationary and move the tool around the material. Although mills can cut wood, they are mainly designed to cut metal. CNC routers are designed to cut softer materials, and are typically less accurate than mills. A CNC router does not require the precision that a mill requires and is a faster option.

After considering our three options, we opted to use a CNC router for manufacturing the Funetic Board. Using a router makes the production of our housing fast, if something changes in the future with our dimensions, it would be easy to quickly remake another updated housing. Also using a router is cheaper than a mill, thus it is advantages when making a prototype that might need to be changed. Also since a CNC router really shines when using wood as a material and the Funetic housing is going to be made of wood, a router is the most ideal manufacturing method for our product.

4.7.4 Dimensions

Figure 25 below shows the dimensions that the Funetic Board housing will have. The board has 6 sphere holes in it, since the longest word length that the board must support is 6 letters (due to our prescribed dictionary). Each sphere needs to be large enough that it is not considered a small part for children, but small enough that the overall length of the board does not get too long. After carefully considering different sphere measurements, we found that a ball with a 3-inch diameter would be the best sizing. Since a sphere has a 3-inch diameter, the pockets that the spheres are set into need a 3 ¼ inch diameter so they fit snugly but are not hard to be placed.

The pockets also have ½ inch edge blends around the perimeter of the circle for aesthetic value. Each sphere represents only one phonetic sound, so we need the spheres to be close together for readability. Each pocket is an inch from the next making it cohesive without being too close together. The total length of the housing is 34.25 inches, which is larger than expected, but when factoring in each ball diameter and multiplying that by 6, it is a necessary length. The housing width is 8 inches, while the height is 6 inches, to have an adequate space for our PCBs and wiring inside.

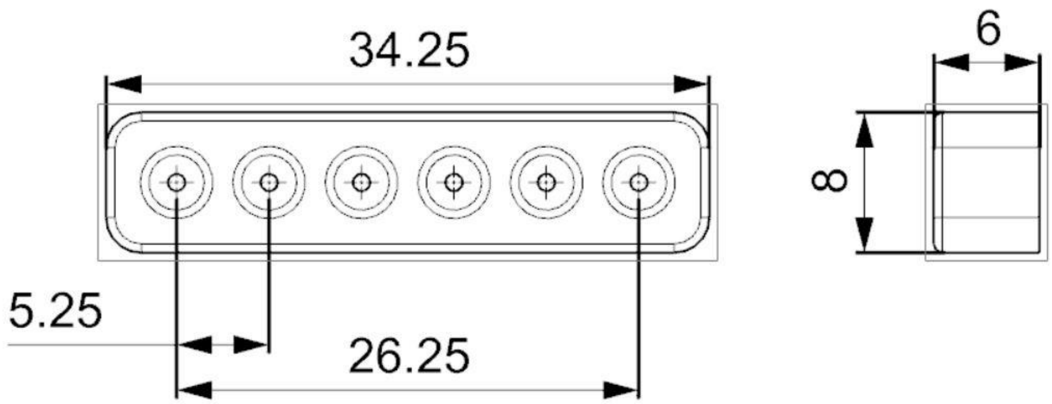


Figure 25 Dimension for the Funetic Board

When initially brainstorming the Funetic Board concept we wanted the housing to smaller and more compact. Unfortunately, after modeling the design on CAD software, we found that it will be much larger realistically than originally planned. If we wanted to make the design more compact, we would need to make the spheres much smaller. For every inch shorter we make a sphere, we are cutting 6 inches from the overall length. As discussed previously, sphere sizing is important because we need the spheres to be large enough to have a clear phonetic sound painted on them. Furthermore, they cannot be so small that young users will be advised not to use our design due to choking hazards. Overall, after reevaluating our design, we are happy with the dimensions being larger rather than having to scale down the spheres.

4.8 Audio Components

Connecting a typical 8-ohm loudspeaker directly to an Arduino is not advisable and results in very low-quality sound. The Funetic Board is designed to help its users with speech and pronunciation problems, and the slightest amount of noise can ruin the nuances of the English language trying to be conveyed. To create the high-quality sound that Funetic Board requires, we will need to integrate an audio circuit into our design.

Creating audio in electronic projects is a surprisingly difficult task, especially if you want high quality sound. There are so many different options available and although many of those options work fairly well, they do not create the quality that the Funetic Board requires. Since audio can be such a cumbersome task, we need to choose the most applicable IC's for our design. Each component has their specific pros and cons, but the slightest misstep in choice can be the difference between clean, crisp sound and a noisy hissing experience.

4.8.1 Operational Amplifier

Choosing the perfect operational amplifier can be tricky, since an ideal op amp is nonexistent. An ideal op amp would be capable of infinite gain and bandwidth, zero output impedance and no internal delay [9]. Even though this model is unobtainable, it is still used as the common model for nearly all op amp circuits [9]. In theory this sounds great, but even though op amps can be viewed as ideal with little to no discrepancies, this does not mean that any amplifier will work on any given design. Op amps have practical limitations in the real world that must be considered based on the requirements of the design. These factors to consider include: bandwidth, slew rate, output current, input impedance, gain, current, offset voltage, and common mode input voltage.

4.8.1.1 Op Amp Comparisons

After doing extensive research, the team found two op amps that are both suitable for our design. The sections below discuss the different specifications of the LM386 low voltage audio power amplifier and the TL072 dual low-noise JFET-input operational amplifier.

4.8.1.1.1 LM386

There are many different ICs to choose from when considering an op amp. The LM386 one of the more versatile amplifier options. It is designed for low voltage consumer applications with a gain internally set to 20 to keep the external part count low, but with an additional capacitor being added between pins 1 and 8, the gain can be increased to any value between 20 and 200 [10]. Although the gain van be increased this does not mean the volume is increased as well. Gain is not to be confused with volume, they are both very different aspects of sound. Gain is a characteristic of an amplifier and it sets the range of possible volume levels [11]. Volume is the sound level that can be adjusted within the levels that the gain provides. Figure 26 below is the internal schematic for the LM386, showing that the LM386 does not have many bells and whistles internally, but is a great general use op amp [10].

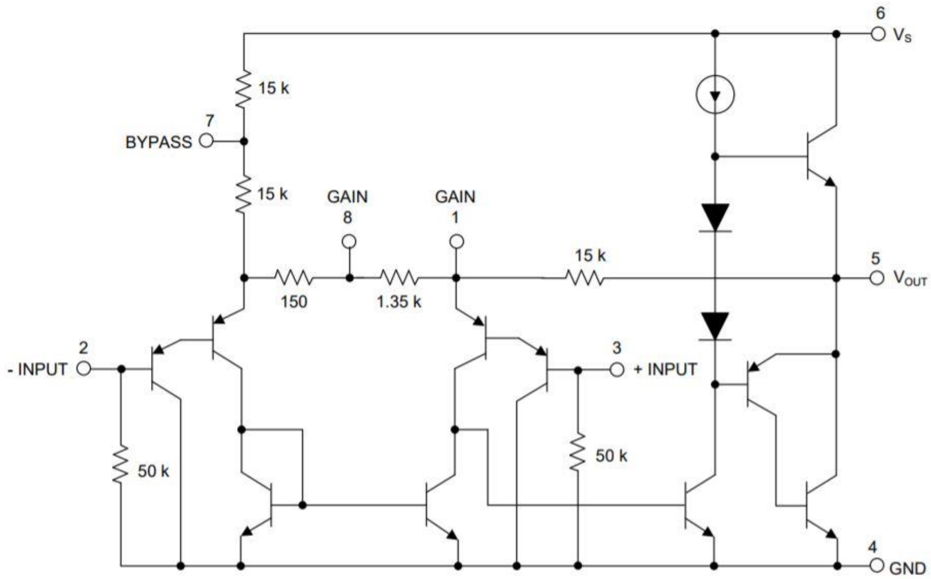


Figure 26 LM386 Schematic (Permission Pending)

The features of the LM386 include:

- Battery Operation
- Wide Supply Voltage Range: 4 V – 12 V or 5 V – 18 V
- Low quiescent Current Drain: 4 mA
- Voltage Gains from 20 to 200
- Ground-Referenced Input
- Self-Centering Output Quiescent Voltage
- Low Distortion: 0.2% (AV = 20, VS = 6 V, RL = 8 Ω, PO = 125 mW, f = 1 kHz)
- Available in 8-Pin MSOP
- Body Size 9.60 mm x 6.35 mm

Although the LM386 specs claim that there are minimal external parts for working sound, that sound quality is extremely low. To have an even close to decent quality, additional components and wiring will be needed. Although the minimum specification will produce sound, when tested, you can hear static, popping sounds, and noise. This problem can be fixed by adding RC filters and decoupling capacitors.

The audio amplifier design shown in figure 27 has a high sound quality with more components than the minimum requirement design in the TI datasheet. The datasheet claims that the LM386 only needs a few support components for working sound; in execution figure 27 shows the minimum number of components needed for the op amp to be implemented in the Funetic design [11]. Resistors and

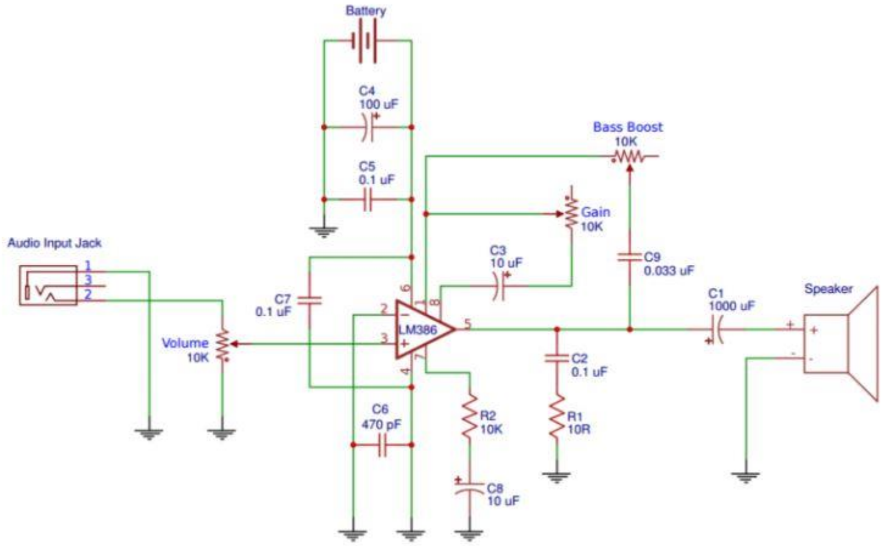


Figure 27 audio amplifier circuit (Permission Pending)

capacitors are added to filter radio interference, filter low and high frequency noise, and decouple both the power supply and the audio input signal. The LM386 also has the added functionality of adding an adjustable bass boost. This is a low pass filter and it increases sound quality by removing even more of the noise. This is done by simply adding a capacitor and potentiometer in series in between pins 1 and 5 [11].

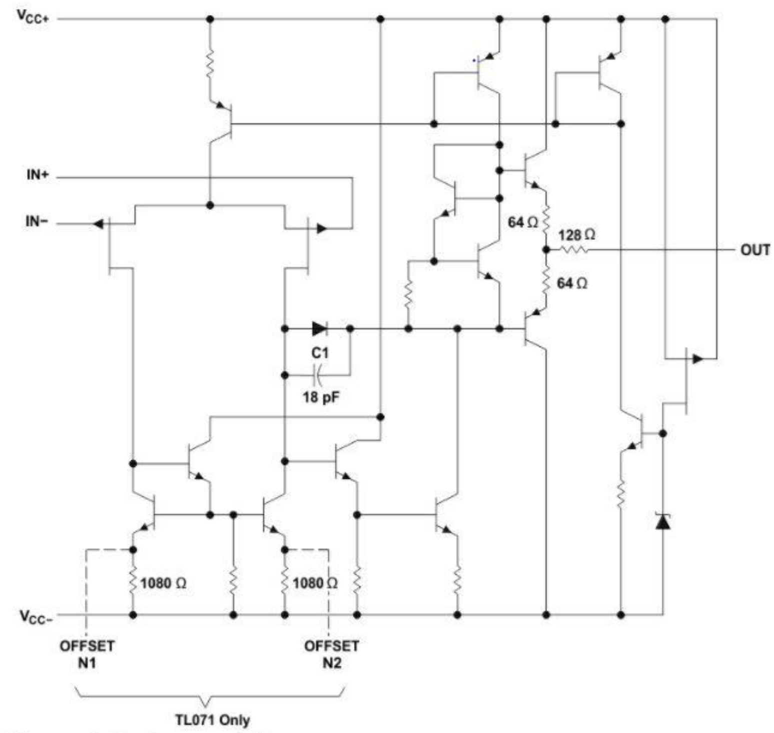
4.8.1.1.2 TL072

The TL07xx is a somewhat advanced JFET-input operational amplifier. It is a monolithic integrated circuit that incorporates well matched, high-voltage JFET and bipolar transistors [12]. Some of the TL072's strengths are having negligible input bias currents and being low cost.

The features of the TL07xx family include:

- Low power consumption
- Wide common-mode and differential voltage ranges
- Low input bias and offset currents
- Output short-circuit protection
- Low total harmonic distortion: 0.003%
- Low Noise: Vn = 18 nV/√Hz (Typical) at f = 1 kHz
- High-input impedance: JFET input stage
- Internal frequency compensation
- Latch-up-free operation
- High slew rate: 13 V/µs
- Common-mode input voltage range includes VCC+

Since this amplifier has low noise and low harmonic distortion, it is commonly used in audio preamplifier and high-fidelity applications [13]. Figure 28 below shows the TL072's internal design, and compared to the LM386 it is quite more complex [12].



All component values shown are nominal.

COMPONENT COUNT†			
COMPONENT TYPE	TL071	TL072	TL074
Resistors	11	22	44
Transistors	14	28	56
JFET	2	4	6
Diodes	1	2	4
Capacitors	1	2	4
epi-FET	1	2	4

† Includes bias and trim circuitry

Figure 28 TL072 Schematic (Permission Pending)

4.8.1.2 Op Amp Final Selection

The LM386 is affordable, easy to use, and simple. The internal gain setting resistor allows the LM386 to be used in a very low part count system [10]. Other chips may perform better but they need more complex circuits. The TL072 is a dual op amp that although it requires much more circuitry to get a working design, it is a low noise op amp, especially so when being compared to a higher noise op amp like the LM386. Overall after analyzing the specs above for our design, the TL072 is a higher quality op amp and with the right circuitry, it will produce a higher quality sound. Since Funetic Board's main objective is to capture each nuanced sound of the English language, it is important to use a higher quality op amp to reduce the risk of noise. Thus, the TL072 will be the op amp implemented in the Funetic PCB.

4.8.2 Digital to Analog Converter Comparisons

A digital to analog converter is an absolute necessity for audio players. A DAC is a simple device that does exactly what its title implies, converts a digital signal into an analog signal. They are extremely popular components with a variety of different designs, prices, and architectures. The following sections discuss the pros and cons of two different DAC designs: The R-2R ladder and the MPC4921.

4.8.2.1 R-2R ladder

The R-2R ladder is the simplest, cheapest and easiest to code implementation of a DAC. Figure 29 shows the design, which can be implemented on a breadboard with through hole resistors, on chip with surface mount resistors, and also inside a packaged IC with highly-matched resistors [14]. The R-2R ladder uses the principle of superposition where switching on binary inputs ass more voltage at the output [14]. The ladder shines in situations where you need to create a very cheap DAC and aren't worried about accuracy. To have a higher quality ladder, the resistors will need to be more accurate and implemented in a chip.

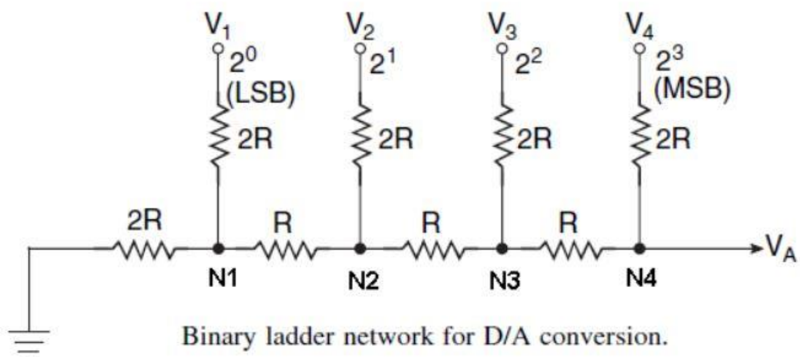


Figure 29 Simple R-2R Ladder Design Permission Pending

There are three stages in the 8-bit R-2R DAC the first stage is made of the resistor chain. This is the stage of the DAC that is what transforms the digital byte into an analog voltage signal. The convention behind this structure is the voltage divider. The most significant bit does not get divided, the second most significant bit has one voltage divider. Then as the bits go on they become lesser in significance, the voltage division is joined across the multiple chain of the branches of resistors. The second stage of the 8-bit R-2R DAC is the first OP-AMP, this is needed to customize the DAC, so it can be designed for a specific application.

The gain of the audio signal can be adjusted by the feedback resistor. This makes it possible to achieve a changing resistance to adjust the DACs gain in the prototype phase. Having this flexibility could be essential during the prototype testing phase. The third stage consist of the second amplifier it is a buffer and will cause a 180-degree phase shift and produces a gain of 1. This buffer reduces the loading effect allowing the loading effect to be insignificant and negligible for the calculations. This is beneficial since the output from the DAC is what will be controlling the speakers, which will have a load. Most of the time a speaker will not have a huge output impedance, although without a OP-AMP the loading effect will attenuate the signal.

4.8.2.2 MPC4921

The MCP4921 is a DAC that utilizes resistive sting architecture and provides low-noise and high-accuracy performance along with low power consumption and an external voltage reference [15]. It incorporates a Power-on Reset circuit to make powering up more reliable as well as allowing synchronous updated of two DAC outputs with its double buffered registers [15]. Another feature of this device is its ability to be operated in two different modes, active or shutdown. These modes can be toggled but setting the register bits pertaining to configuration. The shutdown mode is useful because the amplifier is configured to present a high 500 kΩ resistance output load while turning off most of the internal circuits.

The features of the MPC4921 include:

- 12- bit resolution
- ±0.2 LSB DNL and ±2 LSB INL
- Single or dual channel
- Rail-to-rail output
- SPI™ Interface with 20 MHz Clock Support
- Simultaneous Latching of the Dual DACs w/LDAC
- Fast Settling Time of 4.5 µs
- Selectable Unity or 2x Gain Output
- 450 kHz Multiplier Mode
- External VREF Input
- 2.7V to 5.5V Single-Supply Operation
- Extended Temperature Range: -40°C to +125°C

The rail-to rail output amplifier, input amplifier, reference buffer, and shutdown and reset management circuitry are all shown in figure 30 below [15].

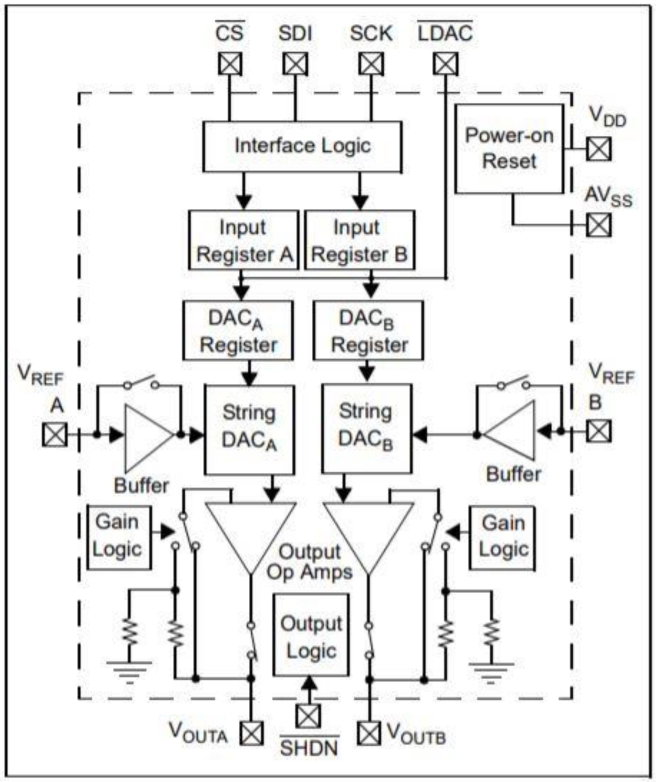


Figure 30 (Permission Pending)

4.8.2.3 DAC Final Selection

If we were using the Arduino exclusively, it would be easier and simpler to use the R-2R ladder design. The R-2R ladder design interfaces with the Arduino nicely and would make coding the DAC a simpler task. On the other hand, the MPC4921 is a much more complicated circuit, and although it might be more difficult to implement, it seems like the best decision for our design. Since we will be implementing our own PCB for the specific Funetic application, using a more sophisticated DAC interfaced with SPI will be a higher quality and streamlined design.

The MPC4921 has many advantages for us one being that it will use less pins than the R-2R ladder. It is very common for an R-2R ladder to use many pins as that is a common downside with that design. Not only does any packaged IC DAC use less pins than an R-2R ladder, the MPC4921 uses even less because of its SPI capabilities. Using less pins is a huge advantage since we need all the pins we can get due to our RFID system using many pins to begin with. Also, our RFID design is already implementing SPI so that added complexity would be easier since we are already familiarizing ourselves with the SPI interface. Not only is the SPI interface and minimal pins on the MPC4921 appealing to our design, it low noise capabilities is especially perfect for the sound quality that we are trying to attain.

4.9 Existing Similar Projects and Products

During the brainstorming stage of what eventually became the development of Funetics it was apparent that the project idea was fairly unique. That being said, the components that make up the Funetics device aren't wildly different from what has been utilized in past projects. The primary aspects that were considered when researching previous projects were use of a wireless communication system as well as use of audio speakers that were needed to provide a decent level of quality sound.

4.9.1 Essence of Music:

The Essence of Music project focused on developing and creating a device for entertainment. With music being enjoyed by all, the aim was to bring an additional layer to the enjoyment of music with an LED light system to make a light show that is synchronized with any music played through the device. This is somewhat relevant to Funetics is a couple of different ways.

As a project with an audio aspect the inclusion of audio speakers was necessary. The decision was made on this project to go with an entirely premade audio hardware package. It is still interesting to note that they chose to utilize a 2.1 system, or, in other words, two main audio channels as well as a subwoofer. The intent with this speaker system was to have a loud output volume level as the device was meant to potentially be used in an environment with a lot of people. This isn't as important to Funetics as the device isn't meant to be used in such an environment. The Essence of Music project also chose an analog filter hardware solution when it came to processing the audio. A digital solution would have provided a flatter frequency response, but the analog solution processes at a much faster rate and provides a higher frequency range [16].

4.9.2 Smart Pet Feeder SPF 2000:

The Smart Pet Feeder, or SPF 2000 for short, is a system utilizing RFID to identify different animals, specifically cats as household pets, coming to get food at a specific location. The system leverages RFID tags to dispense specific amounts of food for different cats. In this project the choice was made to go with the RDM630, the hardware the preceded the RDM6300 that was considered by Funetics. One of the key factors that went towards the 630 being chosen for the SPF 2000 was due to its ability to utilize an external antenna [17].

4.9.3 GRIDI:

The idea of Funetics originated with the discovery of GRIDI, a large, interactive music board. As described on their website, “GRIDI was created by music producer Yuvi Gerstein, with the simple aim, to demonstrate the world of modern music composition and show that musical composition can be accessible and intuitive for all.”

It’s a much large device, the size of a large table, but the core interactive mechanic is the same. Each row is representative of one unique pre-programmed sound, and these sounds are duplicated multiple times across many columns. Small clear balls are then placed onto the device which are used to select musical sound effects to be played. Once placed onto the board the balls are lit up by various different colored lights. A timing mechanism programmed into the device then sweeps through the columns continuously and plays the sounds “selected” by the balls on the board. A musically inclined person can then create short tunes with GRIDI.

Ultimately it was only the interactive model of GRIDI, small plastic balls placed into a divot/hole on the device, that was adopted in the final version of the Funetics device [18].

5.0 Design and Integration

The Funetic Board is designed to be a device that will have audio and visual effects. The device will play a stored audio file that will correspond to a phonetic pronunciation for a word placed by the user. For the visual effects the word will be phonetically displayed on acrylic spheres that will be illuminated by LEDs.

After the research phase has been completed and the parts have been chosen the next phase will be to start the design and integration process of the project. In this phase the objective is to integrate the components to work together, along with integrating the components with the software. When designing the system, the group will keep in mind to develop a design that will not be controlled by a single development board. The design will include a PCB, housing, wiring, and a speaker. The design and integration of these will be discussed in the following sections.

As the integration phase takes place the group will start with integrating the components for the system so that a better understanding of any restrictions that may need to be made or fix to the software. The chosen parts have been selected after careful research, in hope that they will integrate for the full scope of the design. It will be possible that issues could arise that will cause the system to not operate as expected.

If issues and constraints arise the group will revise and modify the design as needed. A couple things that should be considered in the design and integrating phase are, the durability of the design since this device should be able to withstand normal wear and tear, along with the dimensions of the device the device design needs to be large enough to contain all of the mechanisms but compact enough that a small child could interact with the device without issue.

The microcontroller will be in control of the LEDs along with controlling other aspects of the project such as the RFID modules. The power system will use a battery to supply power to the different devices in the system at pertinent power levels. The audio system will be in control of the speaker and the sounds that will be played to the user.

5.1 Hardware

The initial step of the design and implementation phase will be the design of the physical aspect of the project. Included in this is the PCB, wiring, LEDs, battery, and housing. An important thing to keep in mind when designing the hardware for the project will be the wiring when integrating the components. Since we will be using long wires to connect each LED and RFID module to the PCB it will be easy for the wiring to cause issues and become messed up or tangled up with other parts of the design. The process of the wiring will be discussed in the section of the report labeled wiring. Another important thing to consider when designing the hardware will be the cost of the overall design. So, if possible to keep the cost of the design low the group will try to incorporate the use of less expensive design materials without taking away from the quality of the design or affecting the integrity of the design.

The most important aspect of the hardware design and integration will be making sure all of the hardware is able to coincide together

5.1.2 Printed Circuit Board (PCB)

When first researching how this project would be approached it was thought that the Arduino UNO board would be able to handle all the things we need the Funetic board to do such as Light up LEDS using PWM, have DAC and ADC capabilities, produce quality output sound, along with other requirements. After researching it was noticed that the audio projects using Arduino UNO are not as simple as just using the Arduino UNO itself.

Using a LM368 audio amplifier we will be able to get the desired audio results for the project. A PCB will have to be designed to be able to be used along with the Arduino UNO. The PCB schematic will be made using EAGLE software it is a free and allows users to design circuit diagrams with specific values for named components. There is an available library with a range of components to choose from. Components such as resistors, capacitors or power system components will be used in the circuit we are designing which are available for us to use in the design of our system. EAGLE has other basic features that will help us in the design of the circuit.

One valuable feature that EAGLE supplies the user with is the option to create basic or complicated circuit diagrams with labeling for the components. This will allow the user to design a circuit that meets the ideals and requirements of a design aide to fit the needs of the project. Having the capability of designing the appropriate circuit diagram is the first and most important step in designing the PCB.

Another valuable feature that EAGLE has is the ability to generate a virtual board using the circuit diagrams that have been designed. EAGLE is able to show the user a virtual circuit board that can be used to test configurations before actually creating the board. The virtual design can show various design errors that may have been created. An example of a type of error that can be displayed to the user is the size of the component drill holes which could possibly prevent connecting components in the proper way correctly. The PCB schematic for the project is shown in figure 31.

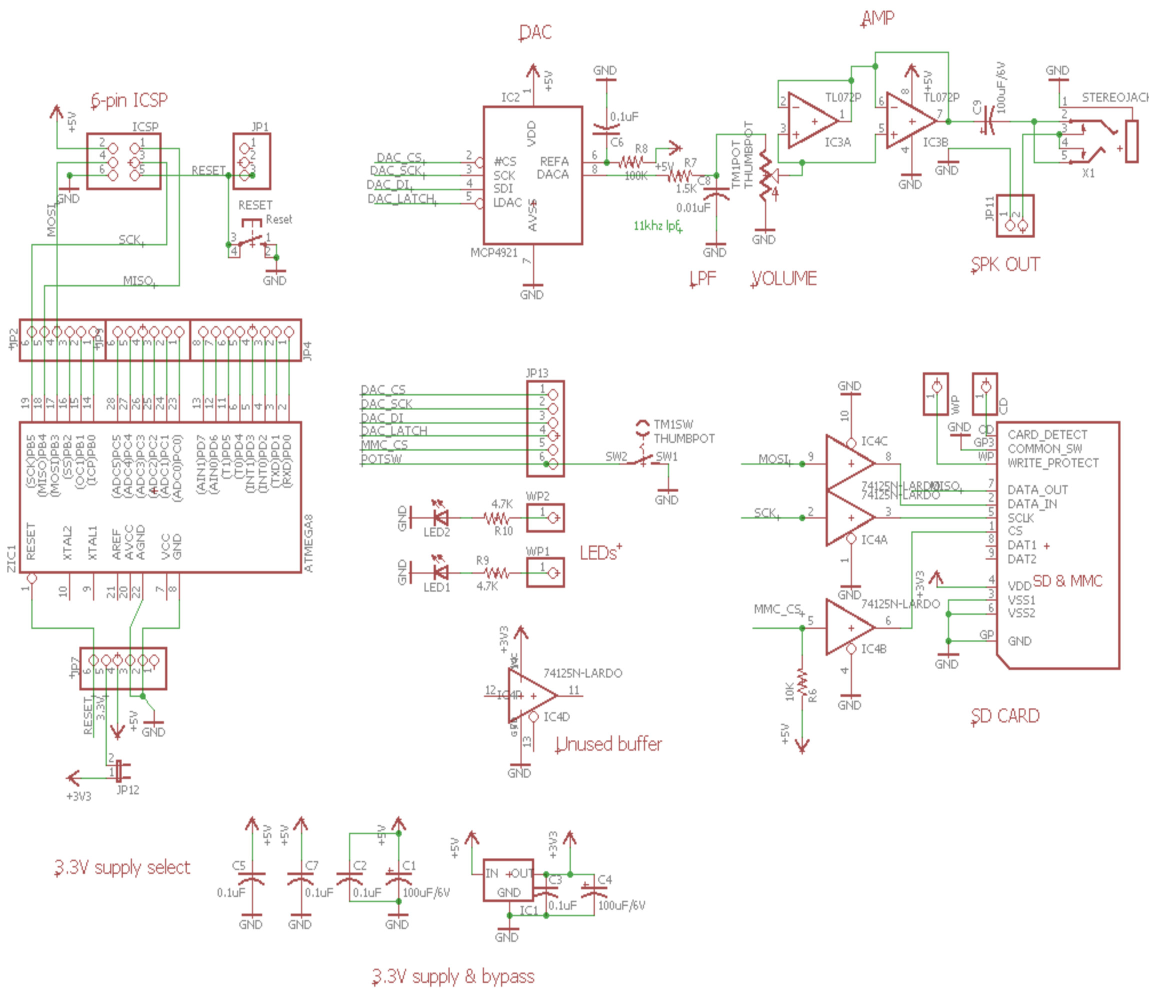


Figure 31 Circuit Diagram for the Projects PCB board

5.1.2.1 PCB Specifications

When designing the PCB for the device there will be a few fundamental guidelines to keep in mind that can easily forgot about. It is easy to get side tracked thinking about the circuit design and component placement. Thinking only about this during the PCB design can cause issues later down the road. To have a design in the end that is reliable, functionable, and manufacturable it is wise to follow a few basic design guidelines.

The component placement is an essential design task that requires crucial thought. This task can be tricky when trying to decide which components can be placed next to each other. A general guide to placing components is to place them in a basic order starting with connectors, power circuits, precision circuits, and critical components. Some other aspect to keep in mind when in this phase of the design are orientation, placement, and organization. Orientation will help during the soldering phase process. Keeping placement is good to think about as to help not place components on one side too close to through hole components on the opposite side. Organization will help keep like components together making the soldering phase easier [19].

Placing power ground and signal traces will also be an essential design task. Power and ground planes should be internally in the board and should be symmetrical and centered. For powering IC's common rails are recommended to use, this will ensure solid large traces, along with being able to avoid daisy-chaining power lines from piece to piece [19]. Connecting signal traces to match with the schematic guide this should be done by making them as short and direct as possible between components. It could be likely that the different nets will have a large scope of currents, this will require different net widths. For low current analog and digital signals, it is recommended to use a .020" width. For .3 Amps or more it should be wider. A trace width calculator will be used to check for required trace widths [19].

Keeping things separate when designing can be crucial to the design. Three things to help with this will be placement, coupling, and amount of separation. Separation is important to ensure that the power ground and control ground are kept separate for individual power supply stages. Placement is crucial because if a ground plane is placed in the middle layer a small impedance path is needed to stop the risk of power circuit interference. Coupling is important to think about when trying to keep things separate to reduce capacitive coupling that is due to placing large ground planes and lines routed above and underneath [19].

The final thing to do to ensure a successful PCB design is to check the final design. There are many websites that offer this type of check. By using EagleCAD this will be a tool that is available to check the final stage of the design.

5.1.2.2 Design Summary and Bill of Materials

The tables below outline the bill of materials for the assembly of our printed circuit board. The PCB will be broken into two different systems. Table 18 shows the BOM for our integrated audio PCB. This PCB has the op amp, TL072, and DAC, MCP4921 described in section 4.8. This PCB uses the DAC, op amp, voltage regulator and other components to convert the digital signal into a signal that can be heard by the human ear and amplify it to the necessary hearing level.

Footprint	Part Info	Description	Qty
TBD	MCP1700-3302E/TO	3.3V linear voltage regulator 250mA current	1
TBD	MCP4921	12-bit DAC	1
TBD	TL072	High-current op amp	1
TBD	74AHC125	Level shifter for SD card	1
TBD	Tyco 2041021-3	SD/MMC card holder	1
TBD	311-1204F-10K	10K or 50K Audio thumbwheel potentiometer.	1
TBD	STX-3100-5N	Stereo headphone jack with switches.	1
TBD	Generic	1/4W 5% 1.5K resistor	1
TBD	Generic	1/4W 5% 10K resistor	1
TBD	Generic	1/4W 5% 100K resistor	1
TBD	Mouser	0.01uF ceramic capacitor	1
TBD	Generic	0.1uF ceramic capacitor	5
TBD	Generic	100uF / 6V or greater	3
TBD	B3F-1000	6mm tactile switch	1
TBD	Generic	6-pin ICSP header	1
TBD	Generic	36 pin male headers	1

Table 18 BOM for the Audio Portion of the PCB

The other system that will be integrated into our PCB is the main board that contains the ATMEGA328 processor. Table 19 displays the bill of materials for this system. This will be the backbone to our main design, while the audio PCB above is a support system. This BOM is mainly based off of the Arduino architecture but will be integrated into a custom PCB specific for the Funetic application.

Blending these two designs together will be the main task for PCB construction. The main board must have everything needed to support the microcontroller, a USB connection, analog inputs, digital input/output pins, and an ICSP header button. Along with those components the main board will have the SPI interface for the RFID's and the circuitry for the LED lights.

Along with the sound implementation and similar to the main board the audio PCB also interfaces with SPI for the digital to analog converter. Although these BOMS are a general list of components the Funetic PCB will have, they are subject to change after testing in Senior Design II.

Footprint	Part Info	Description	Qty
TBD	Generic	0.1uF capacitor	6
TBD	Generic	1uF capacitor	2
TBD	Generic	22pF capacitor	2
TBD	Generic	47uF capacitor	2
TBD	Connector	Conn IC Socket Vert 28POS TIN	1
TBD	Connector	Conn recept 6POS	1
TBD	Connector	Conn header 6POS	1
TBD	Connector	10-WAY sil vert	1
TBD	Connector	8-WAY sil vert	2
TBD	Connector	Conn pwr jack 2.1X5.5MM HIGH CUR	1
TBD	Connector	Conn USB type B	1
TBD	Generic	CER resonator 16.0MHZ	1
TBD	Generic	Crystal 16MHZ 18PF	1
TBD	Generic	Diode 1000V 1.5A	1
TBD	Generic	Diode small sig 100V 0.15A	2
TBD	Generic	Ferrite chip 220 OHM	1
TBD	NCP1117ST50T3G	IC REG LDO 5V 1A SOT223	1
TBD	LP2985	IC REG LDO 3.3V 0.15A SOT23-5	1
TBD	ATMEGA16U2	IC MCU 8BIT 16KB flash 32QFN	1
TBD	LMV358IDGKR	IC op amp GP 1MHZ RRO 8VSSOP	1
TBD	ATMEGA328	IC MCU 8BIT 32KB flash 28DIP	1
TBD	Generic	LED 2X1.2MM 588NM	3
TBD	Generic	LED chipled 570NM	1
TBD	Generic	PTC RESETTABLE .50A 15V 1812	1
TBD	Generic	1M ohm resistor	2
TBD	Generic	10k ohm resistor	1
TBD	Generic	1k ohm resistor	2
TBD	Generic	22-ohm resistor	1
TBD	Generic	Mosfet P-CH 20V	1
TBD	Generic	Varistor	2

Table 19 BOM for the main PCB

5.1.2.3 Soldering Components

The components will need to be soldered to the PCB. There are two main ways to solder components to a PCB. One way is to use solder wire, and the other way is to use solder paste. Both way have their advantages and disadvantages. Also, solder can come in lead and lead-free options this is important due to health concerns with lead. A good solder connection is seen as a ramp or volcano shaped mound of solder. This is shown in figure 32 [37].

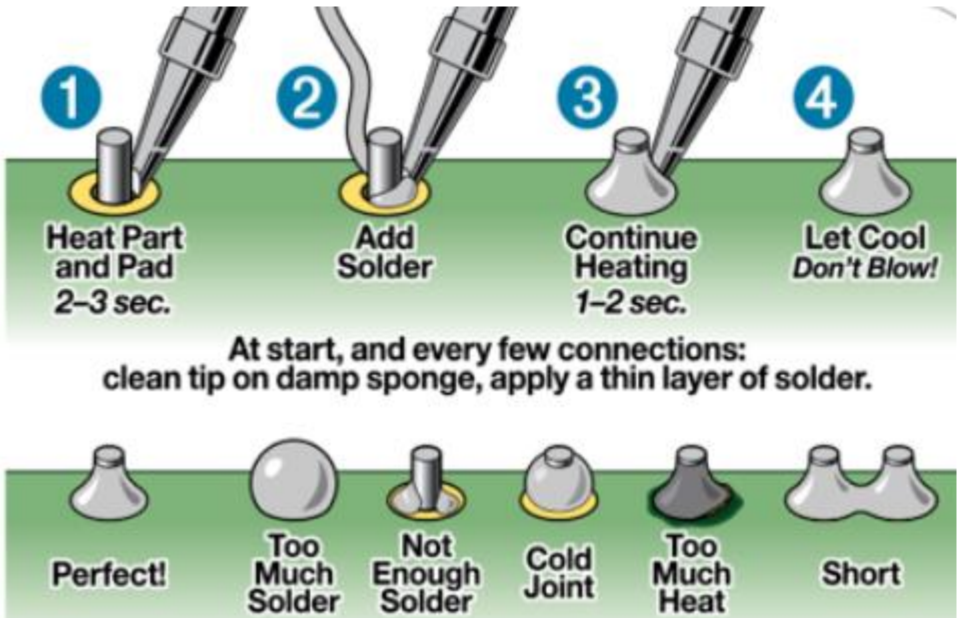


Figure 32 Proper Soldered Joints Reprinted (Permission from Adafruit)

5.1.2.3.1 Solder Wire

One of the ways to solder components to a PCB is to use solder wire. The disadvantage to using solder wire is if the PCB has many components that need to be soldered to the board. This is because each component has a pad it needs to be attached to on the PCB. If a board has fifty components that would need to be soldered this could be very time consuming. Also, when using solder wire issues such as a what is called a cold solder could happen. Also, when trying to solder when small or critical components it could be very difficult to make sure a good connection was made.

The advantages to using solder wire are when less components need to be solder to the PCB this process can be faster and less messy then using solder paste. If the main components that need to be soldered are resistors and capacitors, then using solder wire is a simple process. First the soldering iron is turned and on allowed to heat, once allowed to heat the solder wire is used to wet the iron tip this process is called tinning. Then the iron is gently placed on the desired pad allowing the pad to heat, then the solder wire is touched to the pad to allow solder to melt and adhere to the pad. Once the iron is removed the solder becomes again becomes solid and using a heat gun and tweezers a component and be placed onto the pad by simply applying heat to the pad allowing the solder to melt and placing the component on the pad. Once the heat is removed the solder becomes solid and the component then soldered to the PCB. A good solder is recognizable by the appearance of a ramp, if the solder making the connection resembles more of a bubble it could be a cold solder which is a bad solder and needs to be reheated.

5.1.2.3.2 Solder Paste

Another way to solder components to a PCB is to use solder paste. Solder paste is just a powder metal solder suspended in a thick element called flux. Flux is added to act as a temporary adhesive, holding the components until the heating process melts the solder and makes a stronger physical connection. The paste is a gray, putty-like material. When using solder paste it is best to use a stencil. A stencil is used to apply solder paste to the PCB. It is usually stainless-steel laser cut to create an opening for each surface mount component on the board. Solder paste is not very useful for through hole components since it would be easier to use solder wire with through hole components. Solder paste is most useful for critical components that have many legs or components will ball grid arrays.

5.1.2.3.3 Lead or Lead-Free Solder

When working with lead or lead-free solder a fume extractor should be used. It is a misconception that using lead free solder is safer to use. This is not true because it is not the lead that is harmful it is the flux. When the solder is heated the flux can be vaporized and inhaled which is harmful, the lead is usually not heated to high enough temperature to be vaporized and inhaled. Since the lead-free solder needs to be heated to higher temperatures it is more harmful to use due to the vaporized flux. Lead free solder appears grainy and not as shiny as lead solder this is shown in figure 33. Some of the pros and cons of lead and lead-free paste are shown in table 20 [38].

Figure 33 Balls of lead and leadfree paste (Permission Pending)

Solder	Advantages	Disadvantages
Lead	• Melts at a lower temperature • Rework is easier	• Bad for the environment
Lead free	• Stronger bond • Better resistance • Higher working temperatures	• Melts at a higher temperature • Appears grainy and rough • Needs more aggressive flux • Rework more difficult • More expensive

Table 20 Lead vs Lead free solder

5.1.2.3.4 Solder Decision

For the purpose of the Funetic Board it will make the most sense to use solder wire that is not lead free. This decision is based from two members of the team that work with PCB soldering on a regular basis at their jobs. The PCB board for the Funetic device will have some through hole components and some surface mount. Since the team is trying to stick to a planned budget it would cost more to get a stencil for the use of solder paste, although solder paste could still be used without a stencil it would be extremely difficult to apply the paste without creating a mess on the smaller components. It was also decided to use the lead solder over the lead free due to having a negative experience when working with lead free solder. Also, the group has access to solder wire that is not lead free that will be free to use so we will not need to buy solder wire to use.

5.1.3 Battery Pack

The design of the battery pack will be crucial to the project. It will be used to power the PCB, LEDs, RFID sensors and the speaker. Since the battery will be secured inside the device housing it is important to take in to account the size and weight of the battery along with the expected temperature inside of the housing. With two of the team members having experience with the TENERGY Li-ion battery pack it was decided that this brand would be the most familiar to work with. The battery decided upon is shown in figure 34. This battery has a built in PCB that will stop the battery from overcharging. This is beneficial since Li-ion batteries are known to explode if they are overcharged. Features are listed below [20]:

- Capacity: 5200mAh

- Voltage: 7.4V
- Dimension: 135 x 37 x 18 (mm)
- Weight: 6.4oz
- Maximum charge current: 4A
- Maximum discharge current: 9A
- Cut-off Voltage: 8.4V

Figure 34. Li-Ion Battery pack

5.1.4 Wiring

For the designing and integrating the wiring setup for the LEDs and RFID modules it was decided that it would be best to use heat shrink wrap to cover any components that are loosely exposed and vulnerable. The LEDs will be the most important component to cover with the heat shrink since they will need to have a resistor soldered between itself and the wire that will connecting them to the output pins. This process is shown in figure 35.

Figure 35 heat shrink over exposed leads (Permission Pending)

5.1.5 Power System

For the power system design and integration phase the first thing to keep in mind will be know which components will need to have power supplied to them. The initial research shows that the parts that will need to be supplied power will be, the microcontroller, speaker, LEDs, audio amplifier, possibly a digital to analog converter, and any other basic components in the circuit that could take power when operating the device. When designing the power system for the Funetic Board it will be critical to know the different technical requirements for the components and overall system.

One thought is if the device should be dependent on a wired power system. One of the concerns for using a battery is making sure that the battery is able to be current and voltage limited in order to avoid unstable operation instances. According to the technical specifications, the device should be able to operate the system for at least a one-hour time frame. Another issue of concern that could potentially be is constant power output as the battery drains. It would be very undesirable if the audio or LED output lost the initial quality as the battery lost its maximum power. The LED display show is required to have a constant brightness factor that is enjoyable to the user.

Looking at other similar projects that have been down, it seems that a simple 5-volt input would work to power the device system. After researching it does seem that there are a few different options for powering the device system. One options would be to use AA batteries in series using a battery pack. The disadvantage to this option would be to get the 5-volt input multiple AA batteries would be needed. This would turn out to be expensive and inconvenient to keep replacing them [21].

Even though AA batteries would be a one way to get the Funetic Board powered, it would turn out to be costly and would not be the most desirable option for the design ideals of the Funetic Board. After researching and comparing different options for battery power, the team decided to go with a lithium ion rechargeable battery system. This is due to the systems intentions to be portable, convenient, and modernized, so it would make sense for the device to have a rechargeable battery system. So, the final power system decision was made to implement rechargeable lithium ion batteries as power for the system design.

The reasons for deciding on the lithium ion battery setup for the device are because lithium ion batteries are found easily in different shapes and sizes this one reason it will make them suitable to use in the project. Shape and size will be important because when designing the housing having the option to choose a battery that will fit the design will work to the advantage of the design without having to make modifications to fit the power supply.

Lithium ion batteries also have little memory effect in them - meaning if the batteries are charged to one-hundred percent from fifty percent, it will not affect the total storage size of the battery. Not only do lithium ion batteries refrain from having memory effects, but lithium ion batteries also have a much lower self-discharge rate (about five percent per month) compared to nickel metal hydride batteries and nickel cadmium batteries which have over thirty percent and twenty percent per month of discharge respectively [22].

Even with the advantages to using a lithium ion battery for the system, there is also some disadvantages to using one. The lifespan is one of the more notable disadvantages of using the lithium ion battery option. The lifespan of the battery starts from the moment the battery is manufactured regardless of the amount of times it has been charged and drained. The lifespan also depends on the charge capacity when it is left without use. When it is left with full charge without being used it will still lose about twenty percent capacity per year, and if it is left with fifty percent charge it will lose only four percent charge capacity per year. This means it is better to have the battery not at full charge capacity when it is possible to be unused for any long period of time.

5.1.6 Speaker

After researching many different types of speakers for our application, it has become clear that using a typical 8-ohm speaker should be enough for design as long as the audio amplifier PCB is functioning at a high quality. We are using a 2-inch, 80-ohm 5W full range audio speaker stereo woofer loudspeaker for Arduino. This speaker should be sufficient enough to produce clear sounding audio, we are open to finding a speaker with different specs after the testing phase of our project is complete.

When the Funetic team was brainstorming about speaker integration options a few different ideas were proposed. The first idea was having a built-in speaker inside of the housing device. Another proposed idea was having a wire a standalone speaker wired through and to the outside of the housing. Since building a speaker into the actual housing of our design would be very complicated and could change the way our speaker sounds, we decided to have a hole in our housing where speaker wiring could run through. This seemed like an acceptable idea until we thought about the execution and realized that having soldered wires exposed to the user would go against one of our essential design constraints.

After deliberating further, we found a compromise for both concerns. The best option will be to have an audio jack exposed through the housing for an external speaker to be attached. This solves our wiring problem because now although there will still be a cord, it will be covered, safe, and detachable from the device. Overall, our speaker will be connected to our PCB via an audio jack and will be easily attached and removed from our device. This will not only keep the main electronics from the user but provide an easier solution for our team and speaker integration.

5.2 Software

For programming the microcontroller, the Arduino IDE is written in java but uses Arduino language which is merely a set of C/C++ functions that can be called from various aspects of the sketch code. The sketch simply undergoes minor changes, like automatically generating the function prototypes, then is passed directly to a C/C++ compiler, typically avr-gcc. Though there are a handful of programming languages to use, it is most reasonable to create the code using the Arduino language/C/C++ as other languages don't have much scope outside basic input/output functions and a very limited API. Another programming environment to consider was the official Atmel Studio IDE can also program the chosen microcontroller without any external setup on the microcontroller end. The Atmel Studio IDE supports interrupt monitoring, inline debugging, real-time variable tracking and a full chip simulation.

There were many ways we could have implemented the way the audio would be presented to the user which included, producing the audio of the currently presented combination of letters each time a new letter was added, waiting for the user to press a button to indicate the board is ready to read and speak, or run it on a time based interval that would loop through the board on this arbitrary set interval each time producing the audio for the currently presented combination of letters it saw during the interval

Problems with the first method of producing the audio of the currently presented combination of letters each time a new letter was added are that we were unsure how beneficial it could be and if it could cause confusion for users. Spelling a completed word and having it heard would most likely sound very different if you heard broken apart as you were adding the letters. It could either cause confusion as the almost completed word sounds completely different from its completed variant part and doesn't necessary flow through the progress of speaking it.

On the contrary, there could exist words that are spoken in the correct syllables while being incomplete and adding them all together would produce the whole finished word audio correctly and that process could show how each letter fluidly impacts the word pronunciation. For example, spelling out the word Bee is simple enough phonetically that constructing the letters from start to finish would pronounce audio that make sense to flow logically through the letters. But majority of words even as short as the word "Know", would be a difficult process to comprehend. It simply sounds like the word "no" but if we were to try and pronounce it letter by letter, it would be confusing from the start as you would initially hear a K sound when it doesn't have any sound of K once the word is complete.

Due to constraints and difficulty, it was a consensus it would be practical to implement a set amount, for example a 100 or so, of words that we know for sure would be most beneficial in terms of learning. These set amount of words would be stored in a dictionary along with the corresponding audio file. We can use automated computer voices or self-recorded files using something like Audacity where you can set automatic configurations on exporting the way it needs to be and if it is not already in a .wav file then we should convert to it one. Additionally, our audio bit depth will be set to 8 bits and a sampling rate of 16000 Hz using a pulse code modulation. The results of these settings and configurations will give us a theoretical maximum signal to noise ratio of 48.16 dB computed from using the Shannon-Hartley Theorem.

Using the Arduino Uno, our best bet for audio control is using the TMRpcm library provided by TMRh20 which takes care of a lot of the data manipulation and conversions. The library includes useful functions such as, audio play back able to start at any time interval, disabling/enabling the audio pins which for the Uno we would want to set our speakerPin to 9, controlling the sampling speed, and provides a safe check function that returns a Boolean value if the audio is playing or not.

One of the more notable functions the volume control, it offers sound manipulation on 7 different volume levels which can be incorporated using push buttons on pin 2 and 3 and internal pull up resistors but volume may distort if it set too high. This library can be very processor intensive, and code execution during playback will be slower than normal. Processing load can be reduced by using lower quality sounds encoded at a lower sample rate (8 kHz minimum) Furthermore, it may interfere with other libraries that rely on interrupts. The isPlaying, disable, or noInterrupts, functions can be used to prevent parallel code execution to try and counteract that problem.

5.2.1 SPI

Serial Peripheral Interface, SPI, is a synchronous serial data protocol used by microcontrollers allowing communication between one or more peripheral devices very rapidly over small distances. Also, it can be used between two microcontrollers for communication. With an SPI connection there is always one master device that controls the rest peripheral devices. In practice, there are three lines common to all the devices:

- MISO (Master in Slave Out) – The Master line for receiving data from the slave.
- MOSI (Master Out Slave In) – The Slave line for receiving data from the master.
- SCK (Serial Clock) – the clock pulses which synchronize data transmission generated by the master.
- Then one line that is specific to each device:
- SS (Slave Select) – the pin on every device that the master can use to disable and enable specific devices.

The slave select determines the communication between the master and device. The device can communicate with the master when it has the Slave Select pin set to low. In contrast, it will ignore the master when it is set to high. This functionality allows users to have multiple devices using the same MISO, MOSI, CLK/SCK lines. Figure 36 shows the integration between the Arduino and devices using SPI [39].

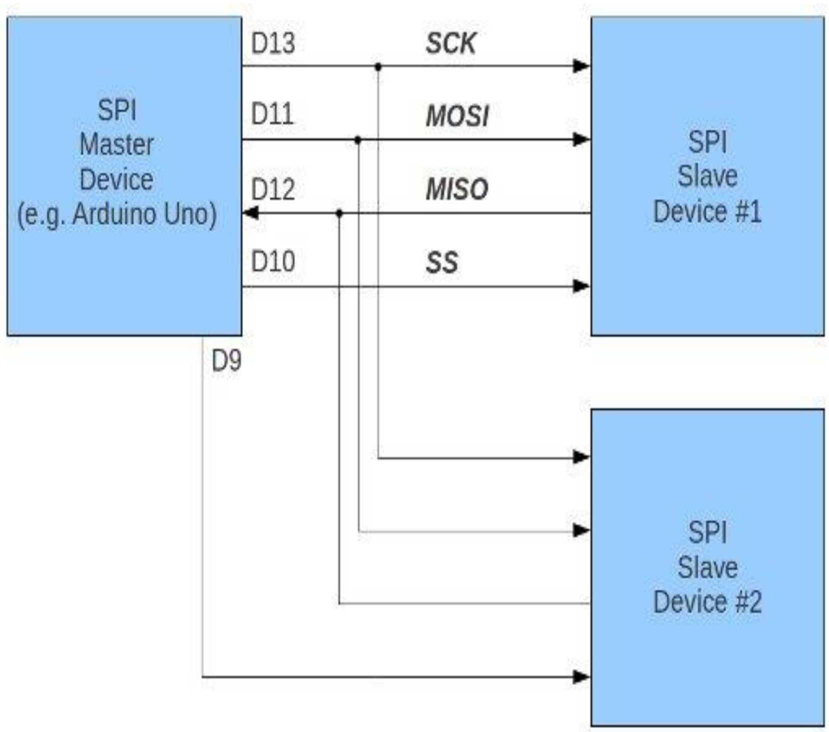


Figure 36 SPI Master-Slave Interface Permission pending

Over the years, standardization has become more common but still lacks small differences between developments. Each device implements it a little different so the standards for SPI are not concrete yet. This results in having to analyze each device's datasheet when writing and producing the code. There are four modes of transmission and these modes dictate whether the data is going to be shifted in and out on the rising edge or shifting in and out on the falling edge of the data clock signal, or clock phase. It also controls if the clock is idle when it is high or low, also known as clock polarity. The four modes and their corresponding functionality are displayed below in figures 37-38 [39].

Mode	Clock Polarity (CPOL)	Clock Phase (CPHA)	Output Edge	Data Capture
SPI_MODE0	0	0	Falling	Rising
SPI_MODE1	0	1	Rising	Falling
SPI_MODE2	1	0	Rising	Falling
SPI_MODE3	1	1	Falling	Rising

Figure 37 SPI Functionality Permission Pending

Once we have inspected our devices and figured out our SPI parameters and included the SPI library in our headers, we can start using the SPI port and configure it with all of our settings.

Arduino / Genuino Board	MOSI	MISO	SCK	SS (slave)	SS (master)	Level
Uno or Duemilanove	11 or ICSP-4	12 or ICSP-1	13 or ICSP-3	10	-	5V

Figure 38 SPI Ports Capability Permission Pending

With the SD card, we can easily store the dictionary of our based words so far. Linking the SD card to the Serial Peripheral Interface bus using the digital pins 11, 12, and 13 which are respectively the MOSI, MISO, and CLK, communication between microcontroller and SD card can be established easily. The Slave Select for the Arduino Uno is used on pin 10 and we can define our chip select to pin 4. Now that we have a direct communication link between microcontroller and the SD card, accessing our dictionary of words and audio files will be an ease. Initially, a binary search algorithm would most likely be the easiest search run time complexity of O(log n) when trying to look up our words in the dictionary due to our constraints and small limited word bank. Though if needed, a hash table can be implemented to provide a much quicker O(1) look up time. This would be more ideal if we were working with a much larger database of words to go through. Another possible structure, since we want to associate our words in the dictionary with the respective audio file, it may be beneficial to create a HashMap where we use the word strings as our keys to hash and search and associate an integer value that maps to which audio file to play.

Recognizing our chosen different phonetics from user input can be done by assigning specific RFID sensors to each unique phonetic spelling sphere. Upon detection of any RFID sensor existing within a certain range, we should attempt to continuously read in the ID tag until we receive the full length of all the characters and concatenate the stored string after each character. Once a full ID tag string is read in and processed, compare that ID to our table of pre-assigned IDs to phonetics to find which phonetic character it belongs to and store our characters until a full spelling is completed. After completing a full phonetically spelled word, we should look it up in our dictionary whether by binary search, hashing, or by keys, and check if that phonetic spelling belongs to any English word we have stored in our SD card and associate it with the matched audio file.

We want to pair the LEDs with the RFID sensors to create a visual representation of the status of the detection system of the phonetic balls being placed. By setting up the serial communication and initiating our RFID reader, as long as an ID is not present we should send to the LED output pins to flash possibly concerning red color. Indicating as if there is something wrong or missing. Once a phonetic ball is placed and detected, we can see that LED change and flash a confident green color to indicate everything is working the way it should and letting the user know the status of their phonetic ball.

5.2.2 File Formatting

With only a 2GB SD memory card that is already going to include the software implementation of the text to speech recognition, microcontroller functions, and any other various information components of the device, we may have to consider ways in which we want to store our audio collection.

5.2.2.1 Wave

Wave is a loseless or uncompressed file format. Strictly speaking, .wav is essentially a container format which just holds various types of audio but mostly used to contain LPCM, linear pulse code manipulation, uncompressed audio. Using wave files, we can collect the raw bitstream representation of the audio signal in a digital form. In theory, an analog signal produced in the real world has an infinite resolution and contains essentially an infinite amount of information due to its constantly changing behavior. So, to encompass this information to the digital domain while maintaining as much information as possible, we need to sample the signal at different intervals to deduct an approximation. The audio signal for wave files are usually sampled at least 44,100 times per second and each sample is recorded. This feature can prove to be very beneficial when manipulating and analysis audio. In figure 39, you can see the analog sound being sampled at every T, which is generally every 1/44,100 of a second or less [40].

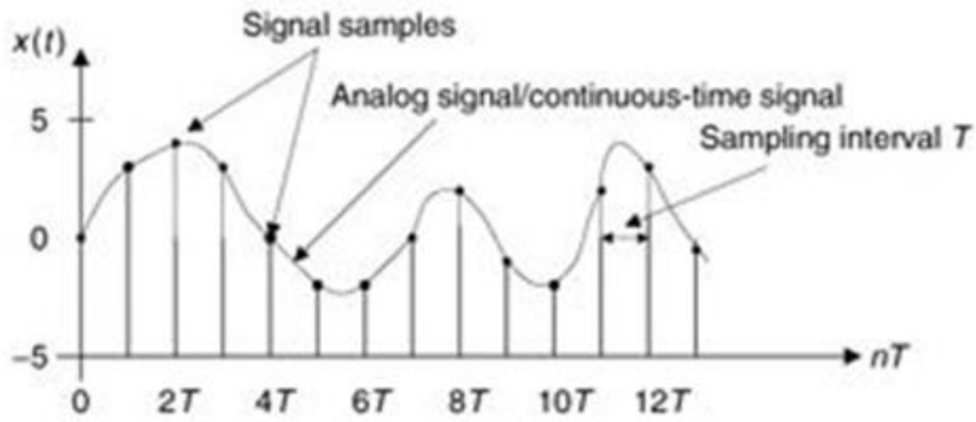


Figure 39 Analog Sampling Permission Pending

5.2.2.2 MP3

MP3 is a compressed or "lossy" file format. It is a great way to attempt to maintain the same audio information just into a smaller size. They are designed in such to keep a respectable level of fidelity all while taking up less room. In simple terms, the compression attempts to delete the unneeded data from the stream and reduce the signal to its most necessary components. MP3s can be a good alternative, especially at high bitrates, to waves when space capacity is a priority. Once you reach a high enough bitrate, the differences between MP3 and wave are probably not even distinguishable to the average untrained ears.

5.2.2.3 FLAC

A good combination of the two, a lossless compression. It has the compression of keeping a respectable level of fidelity that MP3 offers and maintaining the quality that wave offers. Though, still relatively larger than MP3s compression but still smaller than wave. The only problem, most software is not as standardized to FLAC files as common as MP3s are.

File size comparisons of a sample 5-minute recording:

- wave, 16-bit, 44.1kHz: 50 MB
- wave, 24-bit, 48kHz: 82 MB
- wave, 24-bit, 96kHz: 164 MB
- MP3, 128kbps, 44.1kHz: 4.5 MB
- MP3, 192kbps, 44.1kHz: 7 MB
- MP3, 320kbps, 44.1kHz: 11 MB
- FLAC, 24-bit, 44.1kHz: 28 MB
- FLAC, 24-bit, 48kHz: 31 MB

- FLAC, 24-bit, 96kHz: 61 MB

It's a clear difference in space occupancy between MP3s vs FLAC/wave, nearly a whole 15-fold greater memory size of the highest frequency of wave vs the highest bits per second of MP3. Due to our addition of an SD card, we believe the memory should not be too much of a problem and isn't too high of a priority whereas audio quality is a much higher priority. Using wave files would be best to maintain highest quality and could exchange out to our next choice of using FLAC file formatting if memory becomes a real problem.

5.3 Power System

This section will discuss the voltages and currents needed for each sub-system and then check into exactly what power system will be needed to handle these given systems. A need to be precisely specific for each of the subsystems' requirements will require knowing, a range of voltages, currents, and power. Normally, the main concept for concern is the voltage supply. Only concerning the voltage could cause an issue since if the current is not taken into account, it is possible that two batteries will be required in order to provide adequate current. It is not only a circumstance of the voltage needed.

Construction of the power unit will consist of wiring and setting up the batteries into a single casing where they can all be charged conveniently from the outside of the housing. The output voltage will be stepped down using a voltage regulator. The power system is a necessary aspect of the design, so each component needs to be unit tested for proper operation voltages. For testing purposes, all components will all be tested using a 5V DC signal generator. After ensuring proper operation, the team will test the output voltage level from the battery, and then wire the components to the battery.

5.4 Audio

One of our most crucial decisions involved the dilemma of using computer generated voices or using real human recorded voices. Regardless, each decision itself has more choices to break down into. Going down the computer- generated path, we would have to decide how complex and human-like to construct the voice to be. The more clear and human sounding voice would obviously be the best way to aim for, but would we even be capable of producing such a high-quality computer-generated voice.

The process would be difficult and grueling to produce a desirable result but very well rewarding. Whereas, using human recording voices has a much lower skill-requirement. The basic option could simply be mapping words to specific audios but then get as far complex as using human recorded voices to teach the computer to recognize specific sounds and replicate them when needed. This process can be seen in figure 40 [41].

5.4.1 Computer Generated Voices

To understand the foundation of the text to speech problem, it is important to first understand speech synthesis, the artificial production of human speech. The majority of speech synthesis systems nowadays use a large database of high-quality recordings collected from a single person's voice over numerous hours. The general logic procedure we will be following to produce speech using various methods not just limited to these mentioned:

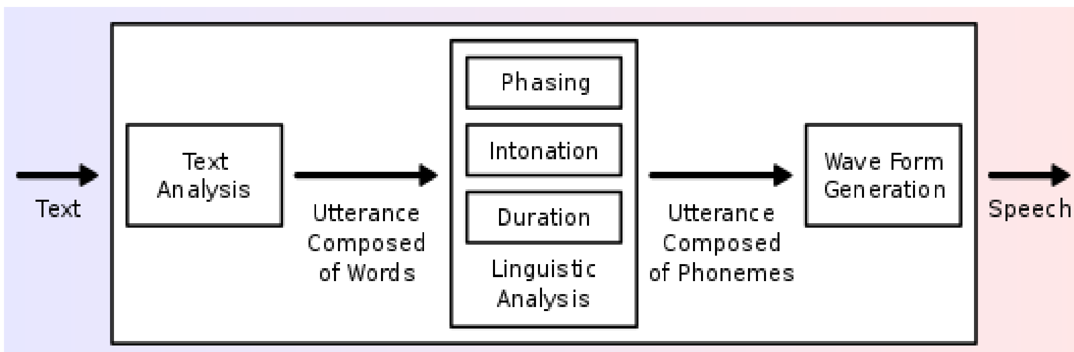


Figure 40 Block diagram for text to speech Permission Pending

5.4.1.1 Concatenative TTS

One human quality voice dependent method is concatenative text to speech. The recordings from the dedicated person are divided into tiny segments that processed and analyzed that can then be recombined, or concatenated, to form any desirable words, sentences, sounds, or even just noise as needed. As long as you have a good algorithm to recognize these recordings and reconstruct them correctly base on the desired word, you should be able to produce any audible outcome. This method though can sometimes result in unnatural sounding voices and become very difficult to alter since a whole new database needs to be recorded each time a set of altercations are needed. Another complication is even switching to a different speaker is problematic without having to record a whole new database. In figure 41, you can visualize the operation of how the sentences would be constructed and this would require a larger memory space since we would have to contain all of our segments [26]. The higher the quality we would want the audio to be would directly correlate to the amount of memory we would need as a larger segment bank would enable more possible combinations of sound and words [26].

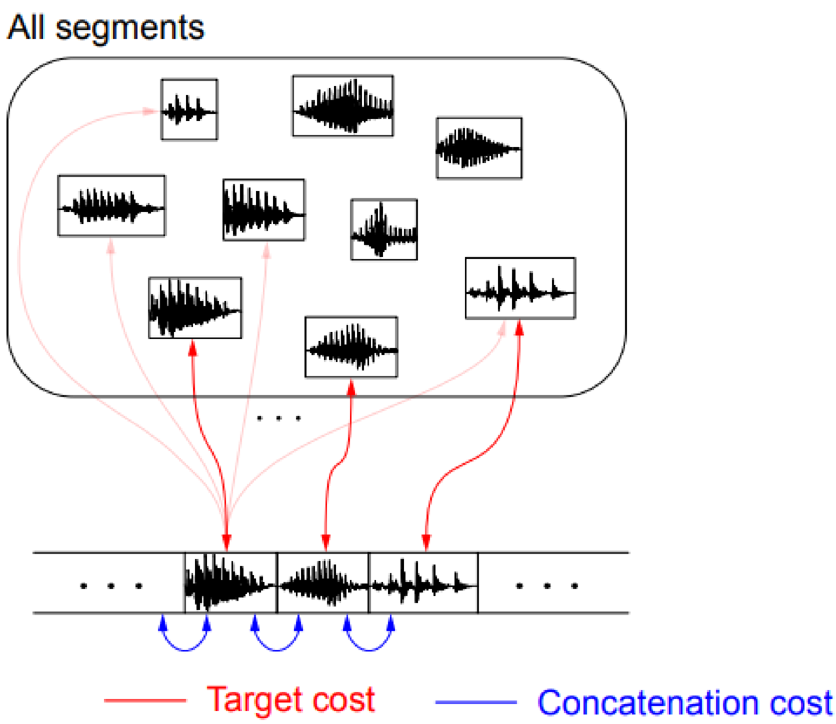


Figure 41 Voice Visulaization Permission Pending

5.4.1.2 Parametric Speech Synthesis

Another computer-generated method, you can use an alternative model known as parametric text to speech. This model gets rid of the need to concatenate sounds by instead using a series of rules and parameters set about grammar and movements/sounds of the mouth to guide the reconstructed voice. On the contrary, parametric voices don't need source materials to produce words. But this independency results in the cost of obtainable a more humanistic voice. At least in English, the outcome is more robotic and unnatural. In figure 42, we have the visualization process for how it breaks down [26]. We can extract the linguistic features from text analysis and the acoustic features from speech analysis where it then goes into our training model. Upon reaching here, it should be able to automatically
construct arguments within a set threshold and generate a synthesized audio [28].

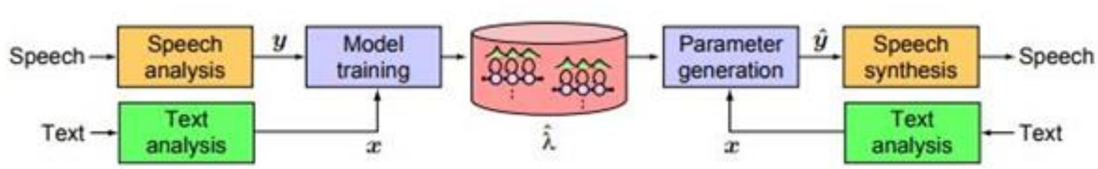


Figure 42 Speech Synthesis Permission Pending

5.4.1.3 WaveNet

WaveNet is a deep generative model of raw audio waveforms. WaveNets are able to produce speech that replicates any human voice and sound better than any of the best existing text to speech systems and algorithms. This approach can reduce the gap with human performance by more than 50%. These are bold statements and alone obviously make it sound like a clear decision to use WaveNets over concatenative text to speech or statistical parametric speech synthesis. But, the procedure itself is quite intensive and the matter is still relatively new and may be beyond our scope and abilities, but we would be attempting our best efforts to try and replicate this process through deep research and understanding.

WaveNet changes the paradigm of these approaches by directly representing the raw waveform of the audio signal one single sample at a time. Previously above, we saw the segments of waveforms being stored in a bank for access to use to construct different sounds, but they looked rather bulky especially when compared to the individual scope that WaveNet will analysis and break down them to. Here we displayed just how significantly different the sample size is going to be between the typical 1 second wave to the 1 millisecond that WaveNet will be sampling. This can be seen in figure 43 and figure 44 [27].

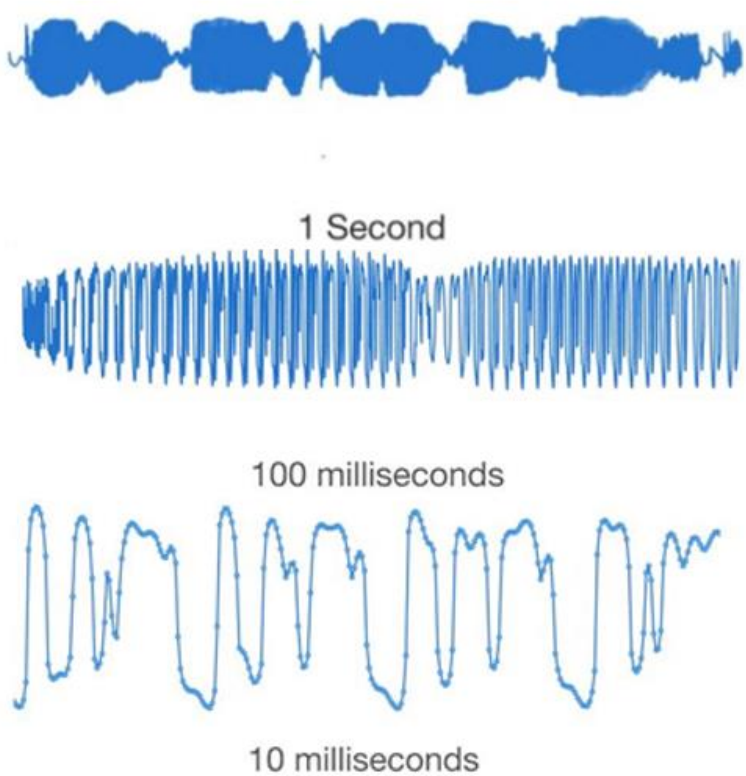


Figure 43 Permission Pending

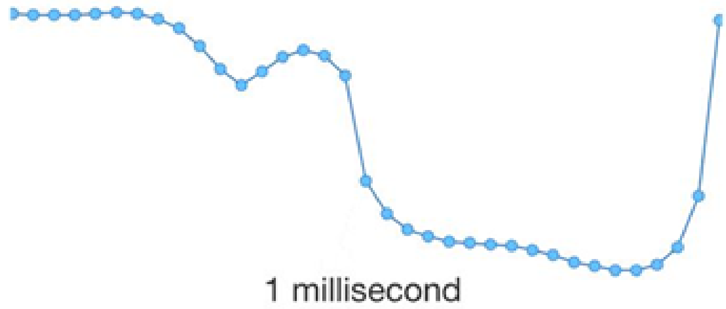


Figure 44 Waveform sampling Permission Pending

When sampling at such a precision, this practically allows the ability to model any kind of audio and sounds. This yields an incredibly more natural humanistic sounding speech. Normally, this approach is always evaded since raw audio ticks very rapidly. You can find usually 16,000 samples or more per second on raw audio, so you can imagine how grueling of a task it could be to process all those samples accurately every second. To overcome such a task, neural networks have become the approach to tackle the problem. A WaveNet is structured in such that it makes a convolutional neural network, where each convolutional layer has different dilation factors which enable its receptive field to develop exponentially. The series of layers between input & output do feature identification and processing in a series of stages, just as our brains seem to do, which is deep learning [27].

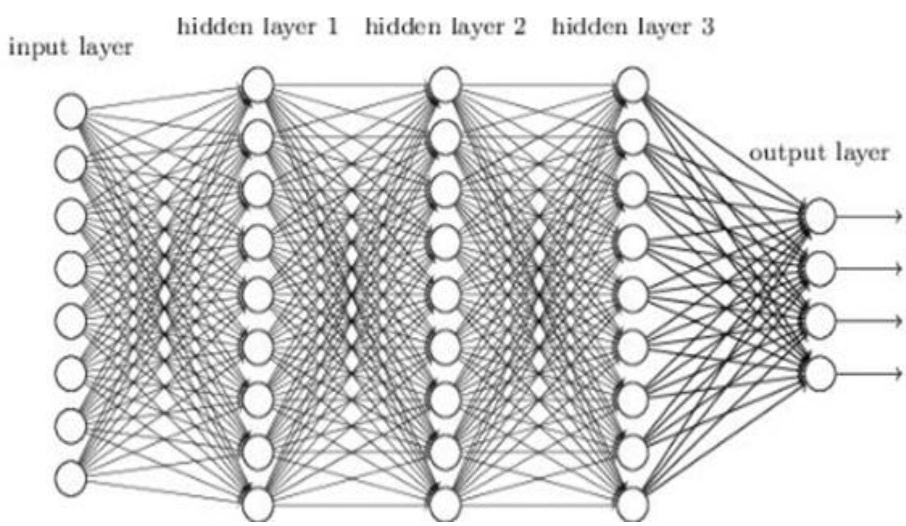


Figure 45 Speech Synthesis layering Permission Pending

In the figure 45, each of the non-output layers, any n number of hidden layers and the input layer, are trained to be an auto-encoder [27]. Basically, it is forced to learn good features that describe what comes from the previous layer. This is what produces the high quality humanistic audio but is computationally expensive.

Concatenate TSS Pros

- Automatic learning
- High quality synthetic voices
- Can be built simultaneously
- Actual instances of speech from database
- Allows diphone synthesis
- Allows unit selection synthesis

Statistical Parametric Speech Analysis Pros

- Automatic training
- Easy adaptation and interpolation
- Small footprint and robustness
- Automatic voice building
- Flexible to change its voice characteristics

Neural Networking (WaveNet) Pros

- Natural sounding voices
- Operates directly on waveform level
- Allows receptive fields to grow rapidly with depth
- If conditioned/trained properly, can simulate different voices
- The more data given, the more precise, very high ceiling potential cap
- Flexible framework

A comparison between trained models using various high-end datasets and normal human speech. A Mean Opinion Score is used as the standard measure for sound quality test in blind test on a scale of 1 to 5. Shown below in figure 46 is the effectiveness goal of raw audio waveform manipulation against other models [27]:

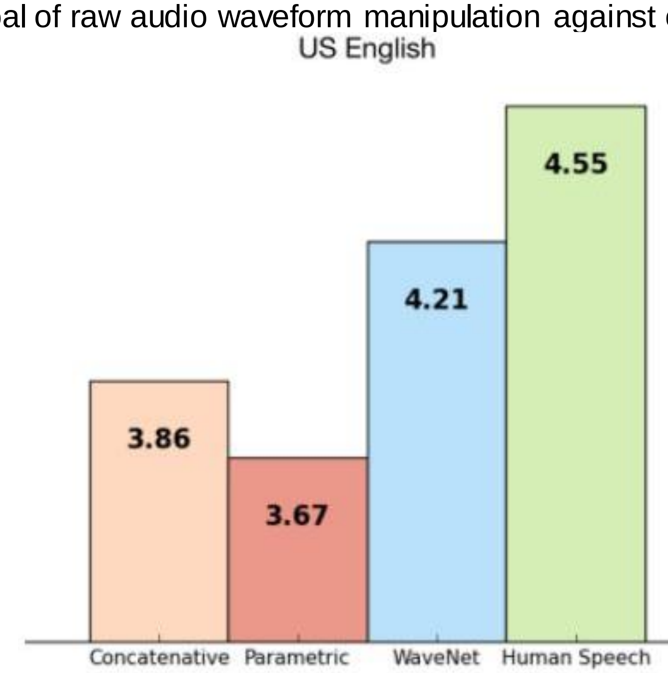


Figure 46 Permission Pending

Ultimately, text to speech computer voice breakthroughs has improved significantly over the recent years and provides many currently provides many advantages than before:

- Voice quality is deemed acceptable and receives close scores to human speech
- Does not seem to derail from the concern of learning effectiveness.
- The only disadvantage we researched but that can easily be overlooked was if users clearly have strong influence on emotions then actual voices showed a more significant margin difference.
- It accelerates development time quicker than a human voice-over.
- Maintaining voice is possible
- Easy to keep the material up to date and precise
- Time and cost makes a significantly lower difference

5.5.2 Human Voices

Using a designated speaker to create voice recordings obviously would sound more realistic than any computer-generated voice. It would definitely provide better results when it comes to our targeted goal of improving and learning English speech but how practical would it be to implement this on a software perspective.

Despite the guaranteed positive results, we would need to contribute hours of recordings after finding someone who has an aesthetic sounding voice. In order to maintain top crisp clear quality audio, altercation to the audio would practically need to be kept minimal if any. This would result in having to hard code and map every single audio file to the corresponding word. That task wouldn't be too bad since we have a limited bank of words in which our device would operate on but having a limitation of functionality on a range of words can be very disadvantageous and a hinder on the potential learning ceiling cap on our goal. To achieve the desired outcome of fully functional on any word, we would need audio recordings for practically every word in the English dictionary.

The most official approximation for the number words in the English language is recorded at 228,000 words, but that was from 1989 by Oxford's second edition. The most recent approximation states the English vocabulary to be approaching almost one million. As you can see, the time and cost required to create and manually map each word to each word is immense in order to accomplish the ability to operate for everything. Since language is ever expanding and evolving, eventually more words come will come into play or words can even depreciate and become obsolete. As this effect continues to happen, it directly corresponds to our device becoming more and more obsolete as well.

In essence, the correlation between full adaptable functionality and the time and cost put into the work corresponds linearly. The more effort put into using human voices is rewarding immediately but only for a specific set of outcomes. The high quality is available from the start, but the quantity is a very long process to complete at a linear rate. Even though implementing a human voice provides better results up front, at what point will it still be worth it when a computer voice will grow at a faster rate to complete full capability of words.

Computer voice	Human voice
• **Lower cost**	• **More authentic**
• **Higher potential**	• **Easier implementation**
• **Less time**	• **More interactive**
• **Minimizes on accents**	• **Precise pronunciation**

Table 21

Table 17 compares the benefits of using either a computer or human voice. The best option for our situation should be to implement and aim for using a computer-generated voice at the highest level and optimize it the best to our ability to the point it almost as good at mimicking a human voice and provide the ability to work on any combination of words or sounds as the time and cost of human voice exceeds our constraints and just sacrifice quality as we hit limitations.

6.0 Design Constraints

Life is filled with many challenges to be overcome, and that's especially true when it comes to designing a product. The Funetics team faces our fair share of hurdles, but the constraints of Funetics aren't insurmountable given the design work laid out. There are many factors that had to be taken into account, not the least of which were time and budget related. For something that's meant to be used by children, safety and durability also have to be accounted for. And in order to create a device that is easy use by the target audience as well as reasonable to produce, factors in the manufacturing process need to be weighed. Finally, as a project that is meant to accustom us to the process of designing and producing a product as engineers, it's also important to consider any potential environmental, ethical, or political constraints that could be put on the end product in any way.

6.1 Time and Economic Constraints

Funetics is not overly complex in hardware design, that being said the Funetics team has limited experience with project design and construction so time must be used wisely. The most time-consuming aspect to the project is construction. More specifically, time is consumed greatly when waiting for parts to be shipped and received. If an incorrect or unwanted part is received, then more time will be used by waiting for newly ordered parts. Prototyping and testing of parts between parts ordering will further consume time. If the team is able to implement a rechargeable battery as the power source then battery life will need to be tested, which will take hours and hours, for example. Physically putting the device together will take time as well. Preparing the body of the device, and mounting the electronics properly inside of the body can't be rushed and will require time to be done with an acceptable level of quality.

Programming, as with any product, can quickly become a time sink. Various aspects are typically developed in silos and then later put together, which rarely immediately works as expected. Debugging the programming of Funetics could take a fair amount of time. The team is not expecting the programming of the product to be particularly extensive. Interfacing the wireless sensor technology properly will likely take the most amount of time given the lack of experience with the technology among team members. The other programming aspect to likely be the most time consuming will be producing the correct audio sound clips via the speaker.

The monetary cost of production isn't expected to be exorbitant. Most of our parts will be standard electronics parts including resistors, capacitors, and small integrated circuits. We will be using a microprocessor utilized by Arduino systems. In order to make the testing process less complicated and time consuming the Funetics team has chosen to purchase an entire Arduino system, which is costlier than only the microprocessor. A not insignificant amount of the budget will also be spent on a wireless sensor capable of writing to the read only sensors.

6.2 Manufacturability and Sustainability Constraints

The manufacturing and sustainability constraints of Funetics are similar to what you'd find with any product meant to be used by the general public, and especially children. The team needs to take into consideration how durable the end product will be, how long the device will be expected to last, and the portability of the product. The materials used to make the device, the size and weight of it, and the power source are all major contributing factors to these constraints.

6.2.1 Durability and Expected Lifetime

Being a device that's primarily meant for children, durability of the Funetics device is a primary concern for the development. Given that the team doesn't have access to the resources required for proper in depth and rigorous durability testing, the Funetics device has an expected lifetime of around five years based on educated estimations. The material of the main device body goes a long way in contributing to the longevity of the device. As such the wooden body should be able to withstand small drops and tumbles. With the intended target audience being small children, precautions have been taken to best seal the device, and as such it should be able to survive small amounts of liquid in the event of a spill. However, it is not expected to withstand large amounts of liquids for any amount of time.

The lifetime of the device will also be impacted by the battery that powers Funetics. It is generally recommended that devices with lithium ion batteries be stored with partially depleted battery levels. Due to the memory aspects of lithium ion batteries, if such a battery is stored left unused for long periods of time the maximum capacity of the battery can and will drop. So long as the Funetics device is stored with a partially or completely dead battery, the lifespan of the battery should last for years.

6.2.2 Portability

Given that the target audience for Funetics are children, it's essential that the device be of reasonable size and weight for them. The aim is to have a device that is no larger than 504 cubic inches, and the longest side being no longer than one and a half feet. Funetics should also weigh no more than five pounds when completed. The Funetics device isn't necessarily meant to be moved around on a regular basis, that being said the target audience is children so with that in mind Funetics should be small enough and light enough so that a child can handle the device on their own.

The intended interactive model for Funetics means that the device must have a minimum size in at least one dimension. The device must be wide enough in order to accommodate the placement of the phoneme balls in a row. It also needs to be deep enough to fit our internal components. None of them are particularly large, but the RFID sensors and the shielding for them will require ample space. Room for the audio speaker also needs to be taken into consideration when deciding the size of Funetics.

6.3 Health, Safety, and Environmental Constraints

For a device that is meant to be used and interacted with by other people it's paramount that Funetics be safe to use by all. The word "Fun" is in the title after. In order for Funetics to be fun it needs to be safe. As a device that's meant to be a child educational tool there are few ways the device could be dangerous. The factors that must be considered in the design of Funetics are the sound levels produced and the brightness of the lights.

6.3.1 Sound Levels

The basic function of Funetics is to playback audio for others to listen to. There are physical limitations to the intensity of sound that the human ear is capable of withstanding without damage and that level must be kept in mind during development. For the human ear, lengthy exposure to sound levels at 85 dB or above can cause damage. Since this device is meant to be used in a teaching environment we have no reason to exceed this sound level. If it is possible for Funetics to get louder than 85 dB, a warning would be included with the device.

It's important to not create an excessively loud device. If Funetics is too loud it could contribute to what is known as noise pollution. The vast majority of people have to deal with noise pollution these days. Noise pollution can disturb the lives of both humans and animals, and has been known to be a contributor of high blood pressure, productivity loss, hearing loss, stress related illnesses, sleep disruption, and speech interference. That last one is very important to Funetics. Most people have been in a scenario where the environment around them is loud and must speak louder in order to be heard by others. Funetics can't be so loud that in the event multiple devices are being used in the same room that a user can't hear their specific device or hear themselves practice the words.

This also needs to be considered in the context of the environment. It could be argued that any loud sound contributes to noise pollution. There is no specific list of sounds that are considering to be contributing factors to noise pollution. That being said, some definitions include sounds that can cause harm to humans. Once again it is important that the sound levels of the Funetics device to be under the 85-dB threshold that is capable of damaging the human ear. This device will be intended to be used in public, and as such it's important that it does not contribute to any noise pollution [23].

6.3.2 Brightness

The Funetics device will utilize light emitting diodes (LEDs) as an aesthetic addition. Because bright lights can be damaging to the human eye and our target audience is children, it is important that the LEDs in Funetics aren't damaging in any way. If a person is exposed to bright sources of light for long periods of time, it's possible for the human eye to sustain damage to the retina. Given that Funetics is meant to be used as an educational tool, teachers and/or professionals over the age of 50 overseeing the user could experience age-related macular degeneration due to the LEDs. It is possible that an over exposure to blue light can cause blurred vision, distorted vision in the form of lines, loss of the ability to discern colors, and loss of contrast sensitivity.

The LEDs in Funetics will be designed to hit a sweet spot such that they are bright enough to illuminate the phoneme balls when placed on the device, but also dim enough such that they don't immediately blind the average person if they are directly looked at. If Funetics were to be made into a production device, it would likely need to include health and safety warnings for the lights within the device.

6.4 Ethical, Social, and Political

With the Funetics device having one target audience consisting of children it's important to weigh any ethical, social, or political quandaries. The last thing the Funetics team, an educator, or any other potential owner of the device needs are angry parents wanting to have words (or worse).

Ethically speaking it's important to consider the possibility of children being able to create words that are considered profane or otherwise offensive. While there is a limited selection of phonetic sounds to utilize (14 to be exact), as the design of Funetics currently stands there is no limitation on how the sounds can be combined. The educational impact of the selected sounds available with Funetics won't be compromised due to only the potential of someone creating an offensive word. At the very least it would be possible to include mock-documentation with the final device warning an owner of this possibility.

If time permits it may also be possible to block offensive words on the software side. A database of offensive words that are possible to be made with the 14 phonetic sounds included with Funetics could be constructed. As the phonetic balls are placed onto the device the corresponding identification tags could be checked against this database. If a flag is set to true the software could block audio from being played if the word attempting to be created is deemed to be offensive.

Alternatively, if the scope of the Funetics project must narrow for one reason or another, the choice may be made to go to a limited database of words that can be made. It is currently planned to have a set of flashcards of suggested words to create, and it's possible the programming itself will be limited to those words. If this is the case, then the ethical problem of offensive words is avoided entirely as they won't exist in the pre-made word database.

Socially speaking, one possible constraint would be the fact that Funetics is limited to the use of the English language. Seeing as the design teamed is based in the US and the primary language there is English, this isn't of great concern. That being said, Funetics as an educational tool could be useful to those trying to learn a second language (or simply those that speak other languages as their primary language). Spanish is a widely used language in the US and would be the first logical expansion for Funetics. Additional language support would be an interesting expansion of the project in the future, but would require at least one expert in any language added to the design.

Politically speaking there's nothing that the Funetics team is aware of that would constitute as a political constraint on the design, implementation, or use of the device.

6.5 Hardware Constraints

Various hardware constraints were encountered during the design and construction of Funetics that needed to be discussed among the team and a decision made upon.

The microprocessor that was selected along with the RFID reader that is being utilized needed to be compatible with one another. The ATmega328 was chosen because the Arduino platform is relatively easy to program for and the resources within the community run far and wide. The MFRC522 is the RFID reader being used as it is meets the specification requirements for the wireless communication needs of Funetics.

Due to a certain number of RFID readers being required, it was important for the processor to have enough of the pins that are needed to operate the RFID readers. Most of the various pins of the MFRC522 such as power and clock can be shared amongst the RFID readers with the same pins on the processor. However, the RFID readers each require individual data lines to the processor, and this is before considering other hardware aspects that may require data lines. This is a primary reason why the -processor- was chosen for Funetics.

Another significant constraint of Funetics was the choice in an audio speaker. Due to the weight and size limitation set upon the device this also limited the size of speaker that could be used in the device. It was determined that a speaker no larger than three inches in diameter could be used for Funetics. With correct speech pronunciation a core aspect to the device, it was also important to find a small audio speaker that would output the level of sound quality required of the Funetics device.

6.6 Software Constraints

With 44 phonetic sounds in the English language and over a hundred thousand words in the English language, programming and testing for all possible words is not reasonable, or even possible, given the size and scope of Funetics. As such, the self-constraint of support for 14 phonetic sounds were programmed and designed into Funetics. These 14 sounds are a combination of the most commonly used sounds in the most common words in the English language, as well as the sounds that people most often struggle with. This is a teaching tool after all. In addition, a collection of 100 words were specifically tested for accuracy. These 100 words utilize the 14 phonetic sounds that Funetics is designed around.

6.6.1 Human Voice Recordings

With the primary purpose behind Funetics being to utilize audio playback to teach others how to pronounce words, it's important that the audio source files being listened to are of a high quality. Therefore, it's of the upmost importance that the person recording the audio is able to clearly pronounce the phoneme sounds that will be used in Funetics. Some of these sounds are commonly used and easy to pronounce for the average person. However, there are also phonemes that are difficult for anyone to pronounce when only the phoneme is being said. For example, there are three different phonemes in the English language that involve the letter “r” that many people struggle with.

This presents two problems for the person recording the audio that will be used in the project. First, they must be able to actually pronounce the phoneme correctly and accurately. If the person designated in the design team to carry out this task is unable to, then another person would have to do it. There's also the problem of getting the recording just right. Somewhat similar to how one may put an emphasis on a word(s) while speaking full sentences, the person recording will need to clearly enunciate the phonemes so that the user listening will be able to recreate the sound themselves. That being said, the person recording these phonemes needs to be careful to not over emphasize the phoneme sounds. Otherwise, when the sounds are put together for full words it's entirely possible that they won't sound right, and that may confuse the user further.

7.0 Project Prototype Construction

Once all the necessary components and equipment have been acquired for the project, and a design has been completed a working prototype will need to be constructed for the project. This needs to be done to verify the practical aspects of the design procedure. Although the prototype is a estimation established with standard practices and engineering conventions, many times prototypes will not properly function during the first attempt. During the prototype development it is essential to identify which engineering predictions occur.

The Funetic Board's final prototype will include the requirements and specifications listed in the technical specifications part of this document in section 2.9. The final prototype will implement the RFID sensors, working speakers, LEDs that light up corresponding to where the acrylic balls are being placed, and a power source that will not be connected to a wall for charging.

The final prototype will be placed in housing that firmly ties and holds everything together. It is possible that the back of the housing will be removable for easy access to the parts.

7.1 Hardware Construction

With so many technical documents and datasheets for the components and software features of the design, the hardware construction of the housing is very substantial. One of the design requirements is to have the hardware fit in the housing with the current dimensions width being 8 inches and height being 6 inches.

The plan for hardware construction will set up the housing that will hold the PCB board, the wiring, and the LEDs on the inside. While the speaker will be setup to sit outside housing, and the phonetic cards will sit on a small platform attached to the housing with brackets. Located on the outside of the box there will be an on/off switch this will allow for better battery control, along with a knob to control volume on the outside. Figure 47 shows the Hardware block diagram for the Funetic Board.

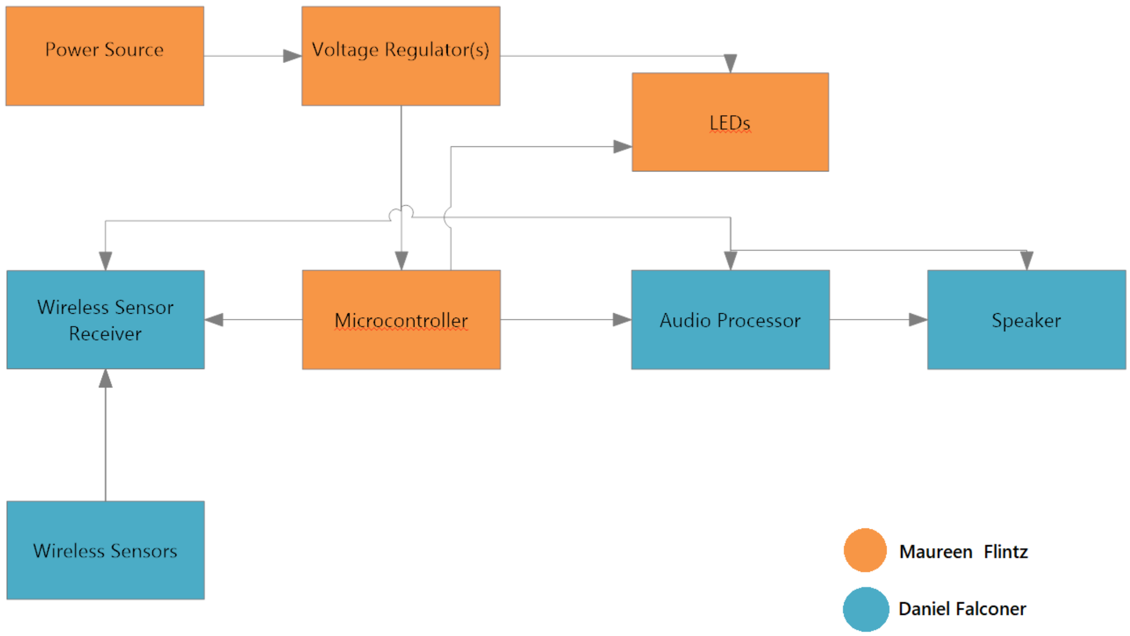


Figure 47 Funetic Board Hardware Block Diagram

7.1.1 Power Unit Construction

The power unit construction for the Funetic Board will consist of rechargeable lithium ion batteries that will sit in a single casing. They will be located in a convenient area where they can be easily accessed for recharging. The batteries will be placed in series to achieve the desired output voltage as needed. This voltage will be regulated by the LM1117 voltage regulator. The power unit is a important part of the design each component will need to be tested for accurate operation power and voltage. To test this a 5V DC power supply will be used. With assurance of accurate voltage levels, the output voltage for the battery will be tested. Then the components can be wired to the battery. The speaker and LED power should also have controlled by the power unit construction.

While constructing the device the use of heat shrink for wiring where deemed Necessary will be used to prevent accidental shorts throughout the system this is essentially important in the design because the cables on the inside of the housing are prone to moving around as the project is being used or transported.

7.1.2 Speaker Construction

The speaker construction for the Funetic Board will be one of the simpler tasks. Once the housing is made, the speakers will need to be implemented. The speakers will sit directly outside of the housing for optimal audio sound. Placing the speaker in the housing could cause unwanted vibrations making the quality of the audio unpleasant. The speaker and will be connected by a wire to the PCB so it is possible that once the housing is design we could use Velcro to attach the speaker to the side of the house for easier transportation or storing purposes. The installation process will be simple once the housing is completed a hole the size of the speaker wire, so the wire can run through the housing to the speaker. Once the placement is decided the Velcro can be attached to the side of the housing for the option of securing the speaker to the side of the housing.

7.1.3 PCB Construction

The construction of the PCB will consist of mounting the PCB to the housing of the Funetic Board. Once the housing is completed the PCB can be mounted to the wood by the use of screws or brackets. The PCB will be placed inside the housing and pencil marks will be made so that we can accurately attach the PCB to the housing. Mounting the PCB to the housing is important because it would be careless to allow the PCB to remain unsecured allowing it to move freely in the housing since this could cause issues with components, they could break or become damaged. Mounting the PCB to the housing will be the most efficient way to ensure the stability of the design.

7.1.4 LED Construction

The construction of the LEDs will consist of attaching a LED underneath the small opening in a socket of the housing, that is made to hold the phonetic balls. Each LED will have an appropriate resistor value soldered to the end of it so they will be in series with each other. The end of the resistor that is not attached to the LED will be soldered to a wire that will then be placed into the output pin of the PCB. Although this design will make use of long wires this option is most useful for this design compared to placing the LEDs on the PCB this is because the spacing of the LEDs are over a distance that would make the PCB much costlier to design if the LEDs were on the PCB.

7.1.5 RFID Construction

The RFID construction will be crucial to having a working device. This is because when placing the sensors if they are placed in to close of range to another they could cause interference. The RFIDs readers will be mounted inside of the housing under the phonetic balls and the tags will be placed inside of the phonetic balls. Wiring will connect the RFID readers to the PCB. After the RFIDs are put into place they will need to be retested to make sure that no interference occurs due to the distance that they are placed.

7.1.6 Housing Case Construction

The housing case for the Funetic Board will be constructed with wood from home depot. The wood should be easy to cut which will help in the construction of the housing. The construction of the housing will be outsourced but the design of the housing will be made by the team. The wood can be tinted or painted to allow the device to be more user friendly or marketable. The housing must be constructed to fit all of the needed electrical components and PCB.

7.2 Software Development

The software prototype development will be a critical aspect of the development phase. This task will be taken on by the two computer engineers on the team. The two main software programs that will need to be coded will be a program that controls the LEDs and RFIDs and a program that will output the phonetic sounds. Shown in Figure 48 is the Software block diagram for the Funetic Board.

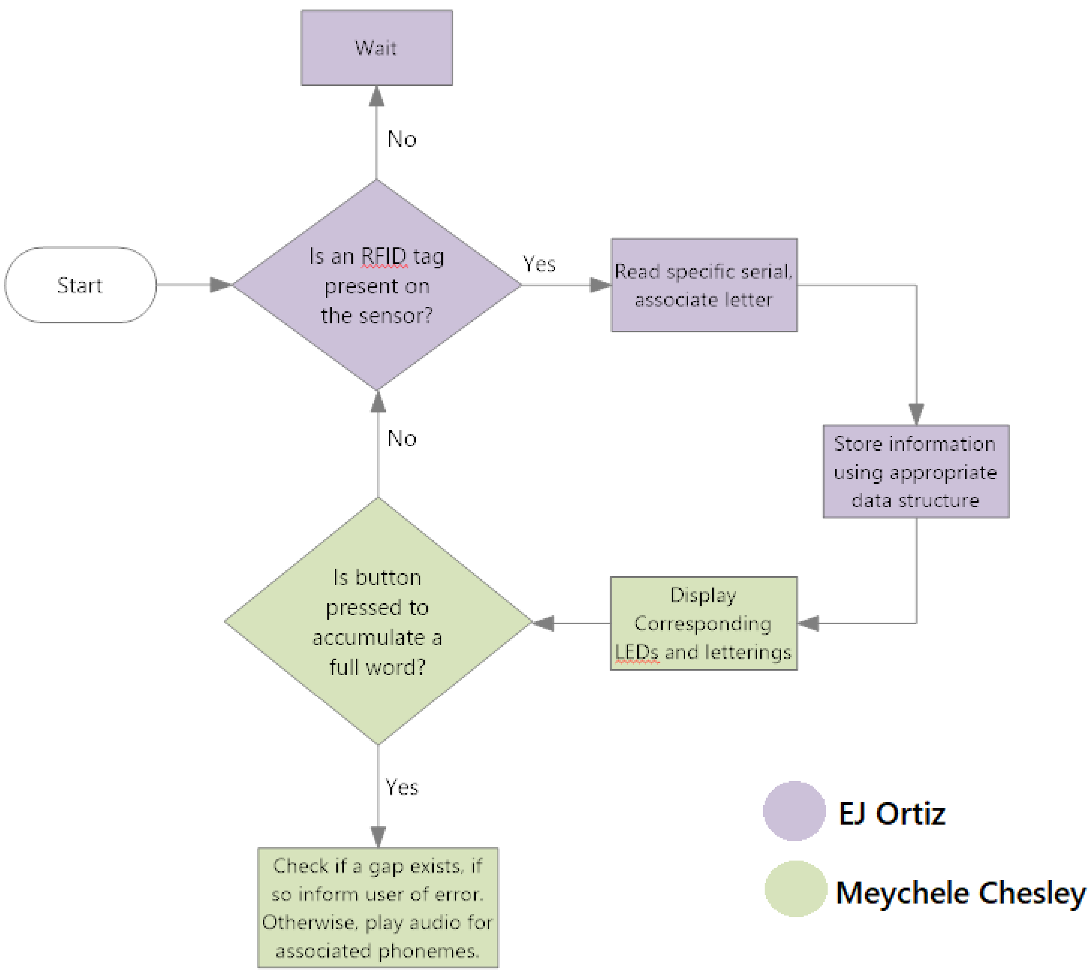


Figure 48 Software block diagram for the Funetic board.

7.3 Prototype Maintenance

Once the prototype has been verified, tested and implemented, it must continue to be maintained. Maintenance routines will vary depending on the type and complexity of the technology. The prototype will be assigned a routine maintenance schedule or program recommended by individuals on the team. The device system should be maintained to ensure that it continues to perform to the level demonstrated during the testing stage. Ongoing auditing or testing plans could possibly need to be put in place to ensure that maintenance needs are identified and met when necessary. If the systems would be put into long-term use, a mechanism could be put in place to monitor feedback from users as another means to determine the need for maintenance and modification. Where modifications to hardware are made as a result of system maintenance or upgrades, it may be necessary to instigate further rounds of system verification and testing to ensure that standards are still met by the modified system. Also maintenance may be necessary if the prototype hardware breaks down or performs below standard. Feedback arrangements for such non-routine maintenance may also be included in the teams' overall maintenance strategy [24].

The most important reason to stay on top of maintenance will be to ensure the prototype works when it is time to be demonstrated. If the device is working before the designated time for it to be observed and the team thinks that everything will be ok until the day of that could cause for many issues. This is why if the prototype is successfully maintained and finished any amount of time before a period of 48 to 24 hours before the presentation then maintenance will be done to ensure that the device says in working condition. The reason why maintenance will be put on pause 24 to 48 hours before the demonstration is due to avoiding any accidental human errors that could cause the prototype to break and not be fixable in the allotted time period that the device would need to be demonstrated in. A check list is shown in table 18.

Maintenance Check	Frequency	Manual or Automatically
Phonetic Balls	weekly	Manual
Wiring	weekly	Manual
Speaker	weekly	Manual
Overall Device	weekly	Manual

Table 22 Maintenance Checklist

8.0 Testing

Outlined in this section are the numerous procedures used for testing to guarantee that the Funetics device will work as intended. Testing procedures will be explained in detail, and included will be the expected results of said testing.
Testing includes:

- Overviews for hardware testing requirements of various components.
- Audio and sound quality testing parameters.
- Procedures for microcontroller, RFID, and power supply testing.
- Software simulations.

8.1 Hardware

Multiple parts that make up the Funetics device as a whole need specific, individual testing before being combined into the final project device. Various aspects including the speakers, RFID wireless communication system, microcontroller, and power system, with the help of some software, will all need to be individually tested, as well as some aspects being tested together before all parts are completely assembled.

As far as hardware is concerned, many components were considered for individual testing. One part that will be of a high concern is the sound system, of which the design was discussed in the previous section 4.6.3.1. It is of utmost importance to this project that sounds be clearly audible to the user. As such, testing of the audio amplifier circuit components and the speaker itself must be done to insure a quality sound experience.

Also of great importance to the Funetics device is the RFID wireless communication system. Without a properly functioning sensor system the fundamental interaction models the project is aiming for will not be possible. The sensor being utilized, as discussed in section 4.6, will need to be confirmed operational with the microcontroller. Functionality in recognizing an RFID tag will then need to be completed. Finally testing can be scaled up to include multiple sensor readers.

Usually it is safe to assume that all parts work properly when they come straight from the factory. That being said, it's important that the design team double check the quality of the parts before implementing them in the final design. This section will examine the testing design for individual parts. If the parts work individually, then it's reasonable to assume that when all the parts are put together for the final device that the device will work. That doesn't mean the final design shouldn't be tested in simulation before assembly. If the final product does not work even though all parts individually passed the testing phase, then it is likely there's a problem with the design in one way or another. Small, basic components such as resistors and capacitors that are acquired in bulk will assumed to all be functional after testing one unit.

8.1.1 Power System

It is ideal for Funetics to be utilized as a portable device so that the user is able to move freely and choose the best location for learning. With this goal in mind, the rechargeable lithium ion battery system that powers the Funetics device must be capable of meeting a few different standards set in testing in order to provide an acceptable amount of battery life.

The built-in battery needs to be able to provide a battery life for an amount of time that would be acceptable in a classroom setting. This means that overall the battery would ideally last a full school day, or more specifically, a minimum of 5 hours of continuous use. The battery life of the device will be tested in a variety of ways, including the following.

The first test done will be for determining how much use time the Funetics device will be capable of. This may require a special testing program in order to function. This test can be run in an environment; acoustics is not the focus of this test. In order to test the battery life of the device while it is in use it will need to be tested continuously until the battery runs out. This means the RFID readers will need to be reading tags, the LEDs will need to be active, and audio will need to be produced by the speakers. It is currently believed that this can be accomplished in one of two ways. Either the existing programming of Funetics will be able to facilitate this by simply leaving a full array of phoneme balls on the device and allow it to cycle through the pronunciation of the word put onto the device until the batter runs out.

If it is not possible to conduct the testing this way, then it will be necessary to construct a program specifically for testing the battery life. This program will be made to leave all LEDs on, the RFID readers forced into a read mode, and the speaker powered and producing audio at all times. In other words, all aspects of the device will be forced to consume their maximum amount of required power at all times.

The battery of course will need fully charged before the test begins. The time at which the test begins will be recorded, and someone will need to be present with the device as the test is running. The time will then be recorded when the device ceases to function. The active use time of the device would ideally be 5 hours. The test will be considered a test if the run time is at least 5 hours. In the even the test is a failure then likely the first option that will be considered for change will be the capacity of the lithium ion battery. A larger capacity battery would increase the battery life of the device. However, that would also increase the cost of the device as well.

In the real world it is not expected that the Funetics device will be in constant use. There will be lengths of time when the device is still on but not in use. This will be referred to as the standby time from here on out. The battery life that the Funetics device has while in standby will also need to be tested. Unlike the previous test, this test will involve the device being turned on, but no components are active. Once again, the time will be recorded at the beginning of the test, and someone will need to be present during the test in order to know when the device turns off from a dead battery. Ideally, the Funetics device would have 10 hours of standby battery life. This test will be considered a success if the device is still on after 10 hours. If the device has additional battery life after this 10-hour test it will not be tested as it is not reasonable to do so. In the event that this test fails, there are at least two options to obtain the goal of 10 hours of standby time. The first would be to test the components with a multimeter while the completed device is on to determine how much power they are pulling. If any components are determined to be wasting power, it will be attempted to alleviate the problem through the software program of Funetics. The second, brute force, solution would be to simply purchase and implement a larger capacity lithium ion battery. A larger capacity battery would result in a longer battery life.

8.1.2 Speaker System

An important aspect to Funetics is the speaker system that plays the phonetic sounds for users via the recorded audio files stored in the on-board microSD card. The Funetics device has to have the ability to play the sounds at both a reasonable sound level and of a good quality. To be more specific, Funetics has to be able to play the phonetic sounds at a level of quality that the user is able to clearly discern the correct pronunciation of the sounds in the word that was made.

Based on research and some preliminary testing it is believed that the speakers chosen for Funetics will perform at the desired levels for the project. Quality seems to be good enough generally speaking. The speakers are loud enough to be heard in a large room with a few people talking at a normal inside volume. Also, all sounds tested can be clearly heard.

8.1.2.1 Decibel Levels

The sound levels produced by the Funetics device can be tested by using the device in a relatively quiet room and utilizing a device called a decibel meter. Also known as a sound meter, this regularly available consumer electronic device is factory calibrated to measure sound levels in decibels.

The decibel meter that will be used for testing the sound system of Funetics is the BAFX Products (BAFX3370) Digital Sound Level Meter. This compact tool was desirable for a number of reasons, and ca be seen in Figure 49.

It is capable of measuring over a range of 30 dBA to 130 dBA. The “A” signifies that the measuring frequency is A weighted, which means higher frequencies are favored more than lower frequencies as the latter is more difficult for the human ear to hear. The A weighting is the standard for sound measuring devices, dBA is the unit of measurement for all measurements of environmental noise, and is commonly used for determining any potential hearing damage from loud noises.

Figure 49 BAFX Products (BAFX3370) Digital Sound Level Meter

The decibel range that the BAFX sound meter is capable of reading is more than adequate for the Funetics speaker system. At the low end 30 dBA is incredibly quiet and nearly impossible for the human ear to hear. At the high end, 130 dBA far exceeds the expected upper limit of the Funetics device. The goal is to come under the 85 dB that is harmful to human hearing if exposed to for extended periods of time. Table 19 shows the technical specification for the meter.

The sample rate for readings of 2 per second should be sufficient for Funetics. So long as the voice samples are played back at a reasonable rate the BAFX sound meter should be able to pick them up within its sampling time rate. The margin of error of +/- 1.5 dB is an acceptable range and should not have a significant impact on testing results. Finally, the measured recordings at the resolution of 0.1 dB is sufficient for the testing needs of the Funetics device project.

Measurement Range	30 dBA – 130 dBA
Accuracy	+/- 1.5 dB
Sample Rate	2x/second
Resolution	0.1 dB
Frequency Response	31.5Hz – 8kHz
Frequency Weighting	A
Power	one 9V battery
Other Features	Low battery indicator Foam windscreen 1/4" thread for mounting

Table 23

The speaker system must be tested to ensure that it's not excessively loud. Funetics is meant to be used in a classroom or similar learning environment. Having a loud speaker that could disturb others in the vicinity of the device and user is not a desirable outcome for the project. The first sound level test will target a value of 85 decibels. This value is important because at sound levels at or above this quantity when experienced by the human era for sustained periods of time can cause hearing loss or damage. The upper value of 85 dB must also be taken into consideration given the potential error of +/- 1.5 dB of the BAFX sound meter that will be used for testing. With that in mind the Funetics speakers ideally would not be capable of producing a sound louder than a measured 83.5 dBA.

The speakers in the Funetics device can't be too quiet either. The sound produced must be clearly audible by the user so that the intended use can be achieved. Therefore, a second test threshold needs to be considered at a value of 40 dBA. Such a value is the typical sound level within a library, which is a relatively quiet environment. If the speaker system produces a sound at this level or lower, it will not be possible for the user to reasonably hear and discern the phonemes that make up the selected word.

In order to test the decibel levels of the Funetics device the testing must take place in a quiet environment. The ideal ambient sound level of the testing environment would be at or close to 30 dBA. However, that may be untenable, and as such it is acceptable for the testing environment to have an ambient sound level measured between 30 dBA and 40 dBA. This is also acceptable for the purposes of the decibel level test due to the fact that the Funetics device must produce sound greater than 40 dB in order to be of use. Ideally the speaker system would produce sounds at or around 50 dBA. At this sound level it would be comparable to a normal conversation between people.

For this test it is also important that the BAFX sound meter be place in a proper position as well as deployed properly in order to pick up sound from the Funetics device. The sensitivity of the microphone array within the BAFX sound meter will ultimately be the determining factor for how far away to place it from the speakers. However, it should be no farther away than the user would be from the device. This will ensure that the sound meter is picking up the same amount of sound that the human ear would be of the user. The average user is estimated to be about 0.5 meters away from the Funetics devices when in use. That being said it is expected for the device to be used by children. In the event they are unsupervised it isn't unreasonable to test the sound levels when directly next to the speaker. So long as this test doesn't exceed 83.5 dBA then it will be deemed acceptable.

It is also important that the BAFX sound meter be deployed in such a way that the environment will not interfere with readings. Microphones are meant to pick up sounds. At their core sounds are vibrations within the air. Therefore, microphones are made to pick up vibrations. A person holding the BAFX sound meter is an acceptable way to nullify vibrations, however said person will need to maintain the same distance during all testing. If the BAFX sound meter is mounted to a tripod, then it must be kept still at all times. It must also be made certain that nothing else on the same surface as the tripod is moving or otherwise causing vibrations. Ideally the BAFX sound meter would be mounted to a tripod with some sort of shock absorbing element.

8.1.2.2 Sound Quality

With the purpose of Funetics to be a learning tool through audio, it's important for that audio to sound as it should and for the sounds produced to not be confused for other sounds. Therefore, sound clarity is an important aspect that must be tested for this device. With the quality of sound being subjective depending on the person listening, the four members of the Funetics project team may not be enough of a sample size to properly evaluate the sound quality. As such, it would be ideal to gather the opinions of a larger body of test subjects.

In order to test the quality of the sound, a similar environment used in the Decibel Level testing (Section BLAH) will be required; ambient environmental sounds below 40 dBA, and otherwise no distracting noises. Test subjects will vary in age, and include both students and family members. The phonemes for words will be said aloud by the Funetics project team in order to provide a baseline for the test subjects. After the tests have concluded with each test subject they will be asked to fill out a survey that will ask them to rate various aspects of the sound quality, including but not limited to; volume, clarity, and playback speed. These three aspects are the most important. Volume mustn't be too loud that it will cause damage, but also not too low that the audio can't be heard. The sounds being reproduced through the speaker must be clearly audible so that the user can replicate them accurately. And finally, the speed at which the audio samples are played back must be at a well-tuned speed so it's not too fast or too slow.

Tests will be considered successful if testing subjects deem the audio quality to be at a suitable volume, be clearly audible, and playback at a reasonable speed. A successful test means the Funetics device is capable of reproducing words built upon phonetic pronunciations that any person could listen to and replicate themselves. Tests will be considered a failure if testing subjects deem any of the three-primary audio quality testing parameters to be of an unacceptable quality. A failure would mean that the Funetics device is not suitable at producing phonetic sounds combined into words that a person would be able to listen to and reproduce. A failure in only one primary testing parameter however could mean only further tuning of the device is required.

If additional test subjects cannot be found, it could be possible to test the sound output of Funetics with an audio recording device. The speaker output could be captured and recorded with a microphone, and the waveform analyzed in some sort of audio production software on a computer. This could then be compared to two things. First and foremost, would be the original sound files of the phonemes used for Funetics. A second test could also be run against a set of speakers known to produce sound at a high level of quality recorded playing back the phonetic sound files. This test would be considered a success if the Funetics speakers recorded waveform is a close match to the original audio files and/or the recorded high-quality speakers. This test would be considered a failure if the waveforms differ greatly from one another. Attempts to make corrections if such a testing failure occurs will be made in conjunction with the information gathered in the previous test described with testing subjects.

8.1.3 RFID MFRC522 Sensors

One of the key aspects to the Funetics device project is the interactive model. As a device that's intended primarily for children it's desirable to have this interactive element. The interactive model chosen requires some sort of wireless communication system, and it was decided that RFID would be the best solution for the needs of the project. Rigorous testing of the RFID system will be needed to ensure that it functions properly and that users have an enjoyable experience.

First, a single RFID sensor will need to be tested with the microcontroller. This basic setup can be seen in figure 50. No one on the project team has experience integrating this kind of technology, so this may be a large hurdle. In order for the RFID sensor to be utilized on the microcontroller, software will be necessary. The software team will utilize a code library from the greater Arduino community in order to get the RFID sensor up and running. Once this is accomplished the RFID sensor's ability to recognize RFID tags can be tested. A simple yes or no recognition program is all that will be needed at this point.

Tests should begin with bringing the RFID passive tag within 1 centimeter of the sensor. This distance is well within the operating range of the sensor and will serve as a baseline. This test will be deemed a success if the software program indicates that the tag was recognized. It will be a failure if it does not. Upon the success of the first test, the distance will be incrementally increased about 1 cm at a time for additional tests. This will continue until a distance of 10 cm, or about 4 inches, is reached. This is the maximum rated operating distance of the MFRC522. With the current design in mind the tags will be approximately 5 cm away from the sensor when they are to be read. This phase of testing will be considered a success if the sensor is able to recognize the tag from a distance of 5 cm.

The next phase of testing will expand to multiple RFID sensor connected to the microcontroller. The MFRC522 units should be able to utilize the same exact pins from the microcontroller that are needed. However, it’s necessary for each RFID reader to have a separate data pin. This is required because each sensor will need to identify different RFID passive tags at the same time the other RFID readers will be reading unique tags. As it is currently understood this data pin is something that can be set in the software, and additional physical pins aren’t necessary. This is the first and foremost thing that must be tested with multiple sensors. If it is determined that this is not how the MFRC522 functions, then it will be necessary to connect each RFID reader with unique physical pins from the microcontroller.

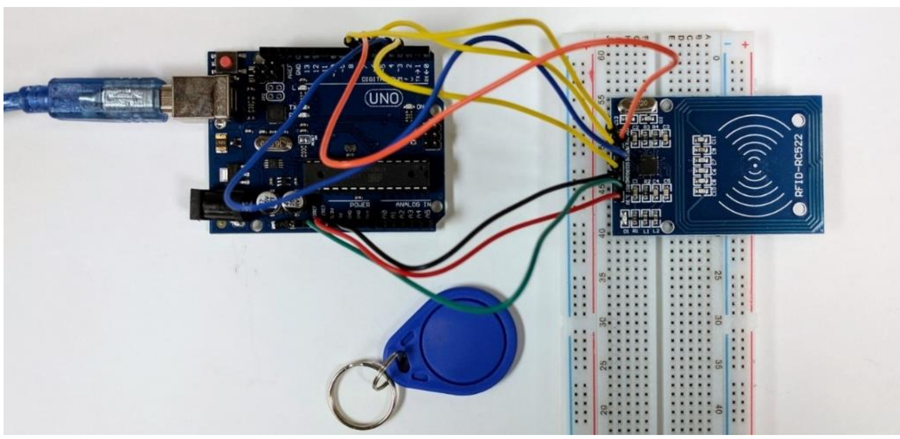


Figure 50 MFRC522 Testing Arrangement

Once two sensors are connected to the microcontroller a test like that which was run with a single sensor will be done here as well. It should be noted that the sensors will need to be at least 10 cm apart for this test. To confirm both readers are able to individually see the tag, the sensors can’t be in range of the same tag at the same time. Ideally for this test the RFID readers will be placed about 20 cm apart, twice the operating range of the antenna on the MFRC522. With two sensors connected a tag will be brought within 1 cm of the sensors and a simple yes or no confirmation program will be running. This distance is well within the operating range of the antenna and will serve as a baseline. The test will be a successful one if the program running confirms the tag was recognized. It will be a failure if it does not. If the first distance test is successful, then the distance tested will be increased at about 1 cm increments for additional tests. These distance tests will proceed until 10 cm, or about 4 inches, is reached. This is the maximum rated operating distance of the MFRC522’s antenna. This test will be considered at test if both the sensor is able to recognize the tag from 5 cm, as well as if the adjacent reader does not pick up the RFID tag meant for a neighboring reader.

The initial design of the Funetics project plans to utilize as many as six individual RFID readers so to accommodate as many as six unique phonetic sounds. If previous tests up to this point have been deemed successful, then similar tests will continue with additional RFID MFRC522 readers added to the build until the desired number of six are integrated. The RFID testing as a whole will be considered a success if all six MFRC522's is able to recognize individual RFID tags simultaneously without interference from neighboring tags and/or readers. If interference is experienced, then additional research may have to be conducted into materials to be used for RF shielding. If it's not possible to get six MFRC522's working simultaneously due to microcontroller constraints, then alternative project designs will be considered.

8.1.4 LED Lights

To make the Funetics device more visually appealing when the user is interacting with it, the decision was made to add LED lights. The lights are planned to function in many ways. It was decided that RGB LEDs will be utilized for Funetics. Given that they can produce a wide variety of colors, the LEDs must be tested to see if the individual red, blue, and green colors look as they should, as well as what other colors are possible of being produced by the combination of the red, blue, and green.

First the lights must be tested for proper functionality. The LEDs will be connected to the appropriate amount of voltage from a power supply as well as the appropriate value resistor for the LED, as discussed in section 4.2.3. Even though the LEDs are a small, bulk order component, they will be soldered in the final version of the project device. Therefore, the LEDs that are set aside for use will all need to be individually tested to ensure proper functionality. The test will be deemed successful if the LEDs are able to produce the colors of red, blue, and green.

The next test will involve connecting the LEDs to the microcontroller. This configuration can be seen in figure 51. It will be utilized in controlling the coloration of the LEDs as the phonetic balls are place onto the device as well as when words are completed. A simple software program will be written to take care of this operation. The goal is to have the LEDs activate once a phonetic ball is placed in a designated location. Therefore, they must be tied to RFID MFRC522's recognition of the RFID tags. This will first be tested with one RFID reader and one LED connected to the system. The test will be deemed a success if the LED activates once an RFID tag is brought within range of the reader.

The next phase of testing will involve testing six LEDs with the full complement of six RFID readers connected to the system. A similar test will be conducted; an RFID tag will be brought into the operational detection range of the RFID reader and it will be observed if the LED activates. This test will be deemed successful if the LEDs turn on when the RFID tags are brought into range of each RFID reader.

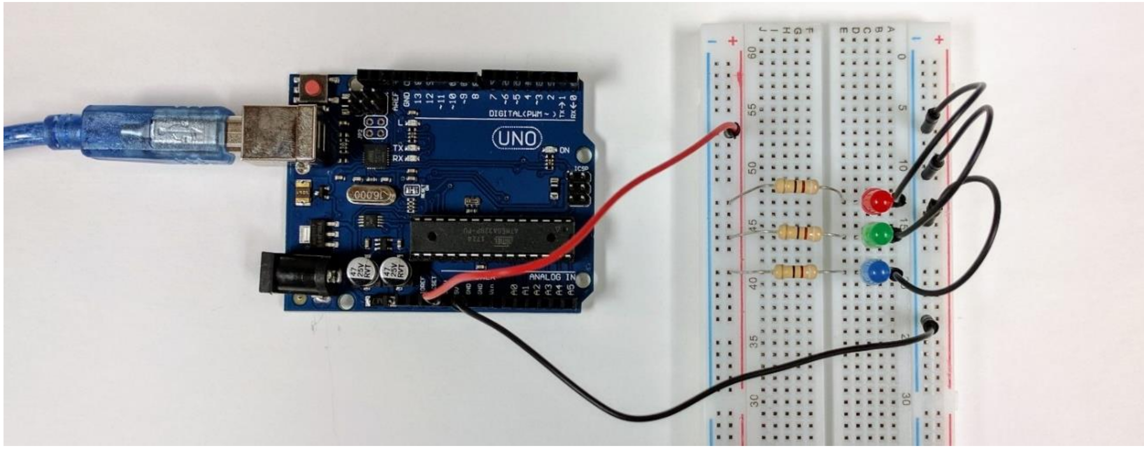


Figure 51 LED Lights Testing Arrangement

The final phase of testing with be changing the colors of the LEDs once a word is completed. As the design of Funetics currently stands, within the software there will be a database of known words expected to be used with device. Once one of the words from the database is made with the phonetic balls, the lights will be made to change colors in an accelerated, or “fun” manner. Once the programming portion of this is completed, hardware functionality will be tested by making the word “apple” with the associated phonetic sound balls. This final phase of testing will be deemed a success if the LEDs act as intended in the program once all the phonetic balls have been brought within range of the corresponding RFID readers.

8.1.5 Use Case Diagram and Description

A use case diagram is a type of dynamic or behavior diagram that is made using a unified modeling language. Use case diagrams are used to model the functionality of a system using users and use cases. Use cases are a set of actions, services, and functions that the system needs to perform. In this context, a "system" is something being developed or operated, such as a web site. The "users" are people or entities operating under defined roles within the system. The use case diagram for this project is shown in figure 52.

The purpose for using a use case diagram is to visualize the functional requirements of the system, that will then translate it into design choices and development orders. Use case diagrams also aid to identify external or internal factors that could influence the system that may need to be taken into consideration. The use of a use case diagram will provide the project will a high-level analysis from outside of the system. It specifies how the system interacts with the user without worrying about the details for how that functionality is implemented [25].

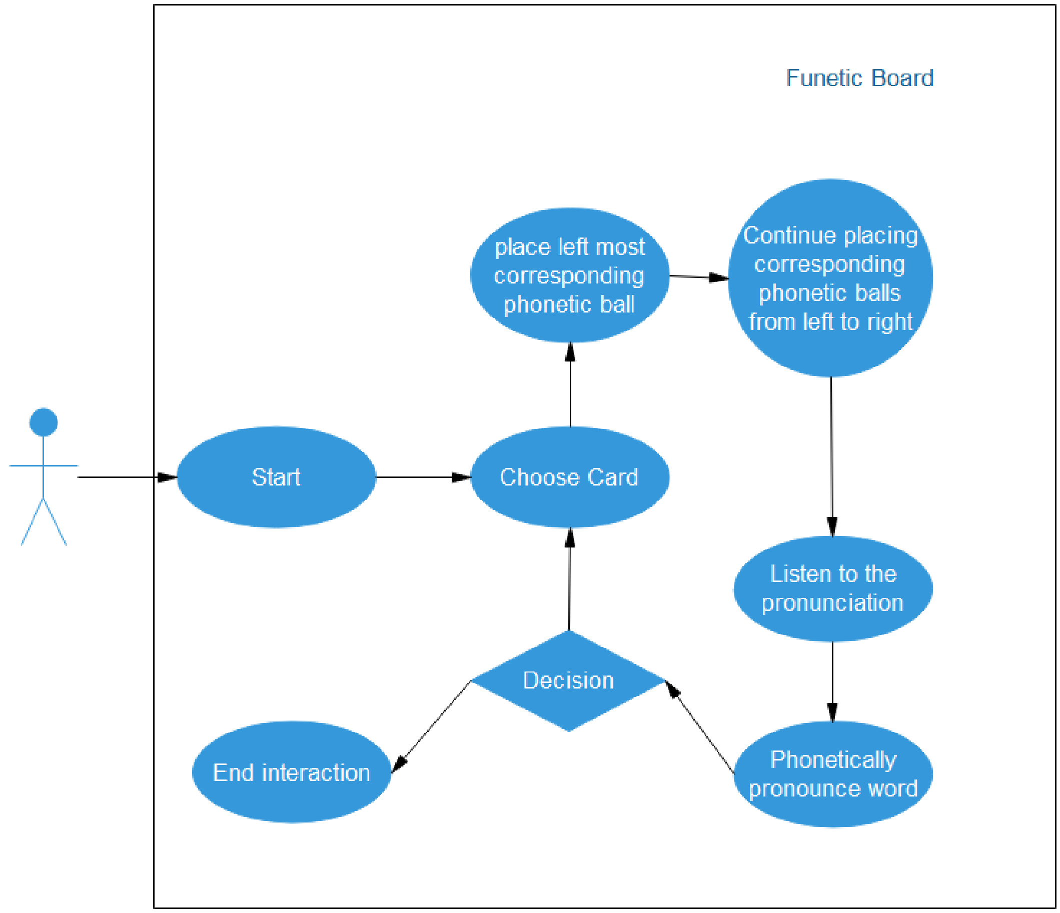


Figure 52 Use case diagram for the Funetic Device

8.2 Software

Software testing is the process of evaluation a software item to detect differences between given input and expected output. Also, to assess the feature of A software item. Testing assesses the quality of the product. Software testing is a process that should be done during the development process. In other words, software testing is a verification and validation process [19].

There are many types of software testing that will help aid in making sure the design in successful. The following software testing procedure will be done to ensure that the device will be working at every stage and step of the design.

- Unit Testing
- Integration Testing
- Functional Testing
- System Testing
- Stress Testing

- Performance Testing
- Usability Testing
- Acceptance Testing
- Regression Testing
- Beta Testing

8.2.1 Unit Testing

Evaluating the different methods is needed in order to validate the functionality desire which is satisfactory to our goal. The software process will involve unit testing where the development process will take individual pieces of the application to make sure the implementation producing the expected output given specific inputs. After each and all units pass through the unit testing portion and is approved satisfactory, it will proceed into integration testing where the groups of components can be combined to produce our desired content. This will be the interaction between software and hardware components. This is one of the earliest and smaller scales to do early on. We would conduct unit testing initially on the audio files individually to make sure that each phoneme, the word construction, and final words are being produced correctly and sound the way they are supposed to sound. Below in figure 53 is the hierarchy of the levels of testing it will go through [42].

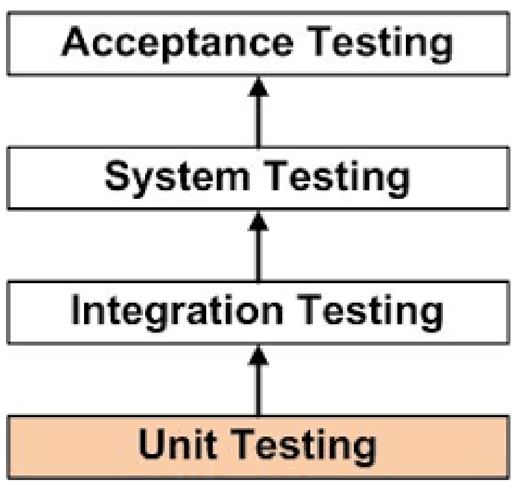


Figure 53 Unit testing hierarchy

8.2.1.1 Python Testing

The Python module for unit testing framework known as “PyUnit”, is Python’s model of “JUnit”. Junit is an open source framework that can be used for unit testing for Java programs. The testing framework creates a new test class that utilizes the already existing class to verify their main methods. This checks the returned value from the existing class and compares it against the true result. Another test framework in python created by a third party called “py.test” is a fully-featured and extensible testing tool similar to “PyUnit”. The main difference between the two is PyTest can accomplished the same result as PyUnit but in a less complex syntax which results in a cleaner more user readable code. This simplicity though also leads to a lesser cap in more flexible functionality. As long as we don’t need anything too complex, Py.test should offer everything we need to create and check audio code snippets. The easier readability will be beneficial to let everyone understand what is happening in the code and allows more of the non-software oriented based people to create multitude of unit test cases at a relatively quick pace which will lead a faster process time in the development. With Python and the python testing modules, we can easily create snippets of audio phonemes, sentences, specific syllables, or any sounds required. This allows us to individually play and test single pieces at a time before reconstructing them into the final version. The block diagram in figure 54 displays the process for python testing [43].

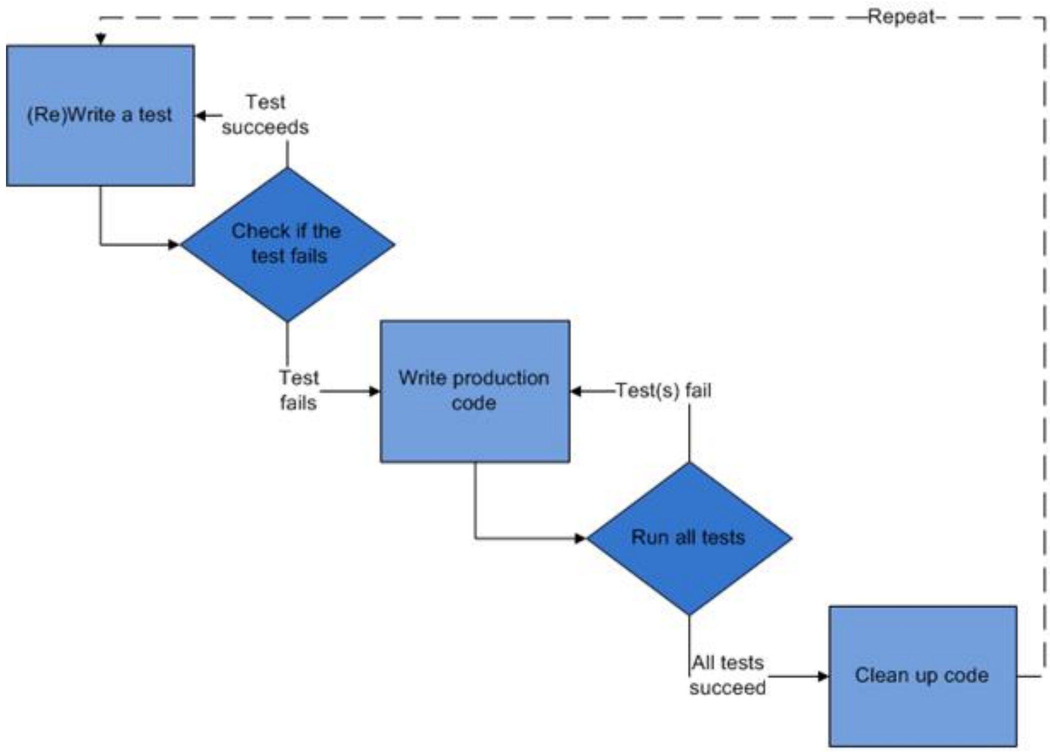


Figure 54 Python testing block diagram

8.2.2 Integration Testing

The integration testing process will test the integration between the devices components, the interactions to different parts of the system such as an operating system, and the file system and hardware or interfaces between systems. For instance one module will be tested then another module will be test then both modules will be tested together. Figure 55 shows a Venn diagram of how integration testing can be accomplished [42]. This could be considered both white box testing and black box testing. Specifically, we want to verify that the microcontroller is able to correctly interact with the SD card to access and read the necessary files and if needed to, also write to the SD card for possible functionality looking forward in the project's scope.

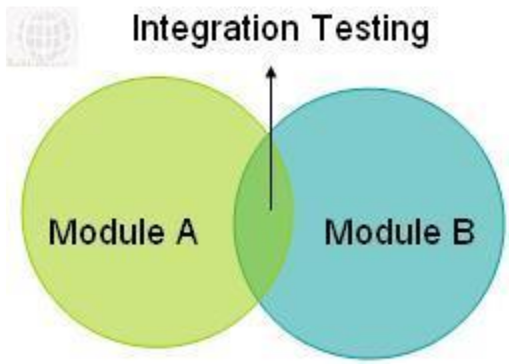


Figure 55 Venn diagram for integration testing permission pending

8.2.2.1 White Box Testing

White box testing is a technique term used to describe a testing procedure that takes into account the internal mechanism of a system. It is a way often used to ensure verification.

8.2.3 Functional Testing

Functional testing is the procedure of experimenting with the products to ensure that our specified functionality requirements we set out for it to do are indeed working the way we intended for it to work. This can be considered as falling under the class of black box testing. We want to make sure that we can first test the functionality of the microcontroller's ability to correctly read and distinguish between different and multiple RFID tags all within close proximity of each other. Then, we want to test the functionality between the data associated with each RFID tag is correctly corresponding to the right sound it needs to call. Furthermore, we need to make sure the functionality of the microcontroller being able to interact with the SD memory card and is pulling the correct files mapped to it. Lastly, we should ensure that the audio file is able to play without problems. Figure 56 shows a simple block diagram for functional testing [44].

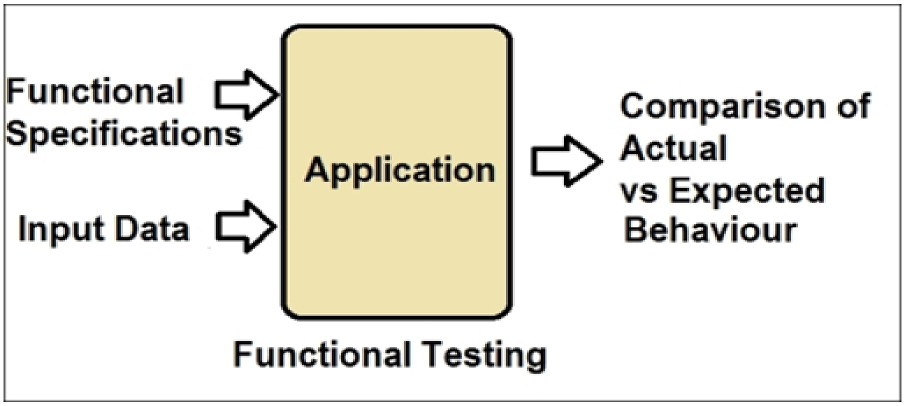


Figure 56 block diagram for functional testing

8.2.3.1 Black box testing

Black box testing is a technique term used to describe a testing procedure that ignores the internal mechanism of the system and focuses on the output generated against any input and execution of the system. It is often used as a method for validation. A comparison for black box and white box testing is shown in table 24

Black Box Testing	White Box Testing
• Software testing method in which the internal structure implementation of the item being tested is NOT known to the tester	• Software testing method in which the internal structure implementation of the item being tested is known to the tester.
• It is mainly applicable to higher levels of testing such as Acceptance testing and System testing, considered functional testing.	• It is mainly applicable towards the lower levels of testing such as unit testing and integration testing, considered structural testing.
• Testing technique is generally done by the software testers	• Testing technique is generally done by the software developers
• Programming knowledge is not required	• Programming knowledge is required
• Implementation knowledge is not required	• Implementation knowledge is required

Table 24

8.2.4 System Testing

System testing is the procedure of conducting experiments to help ensure that by putting the software in different environments it should still be able to work. For example, running the same program on a different computer or different operating system and still working the way intended. System testing is done with full system implementation and environment. This additionally falls under the class of black box testing. Figure 57 shows a Venn diagram explanation for system testing.

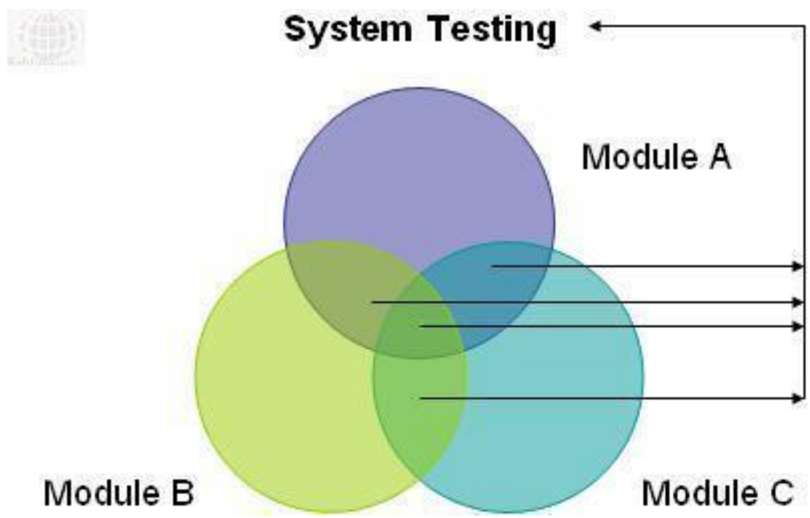


Figure 57 Venn diagram for system testing

8.2.5 Stress Testing

Stress testing is the process of conducting series of experiments to assess the speed and effectiveness of the system and to make sure it is producing the desired results within the respected time as stated in our requirements specifications. This falls under the class of black box testing. We want to make sure that the speed class of our selected SD card is performing up to standards. Also, it is ideal to test long periods of repetitive usage of the device to ensure it is able to perform optimally with little to no change in performance.

8.2.6 Performance Testing

Performance testing is the procedure which is done by end users, the people not closely involved in the software development process. They are responsible to hopefully perform a full test run of the nearly completed product only to make minor tweaks and adjustments found in this beta version, the last revision before final release, and ensure we cover all unexpected errors. Figure 58 shows the procedure for how performance testing is done.

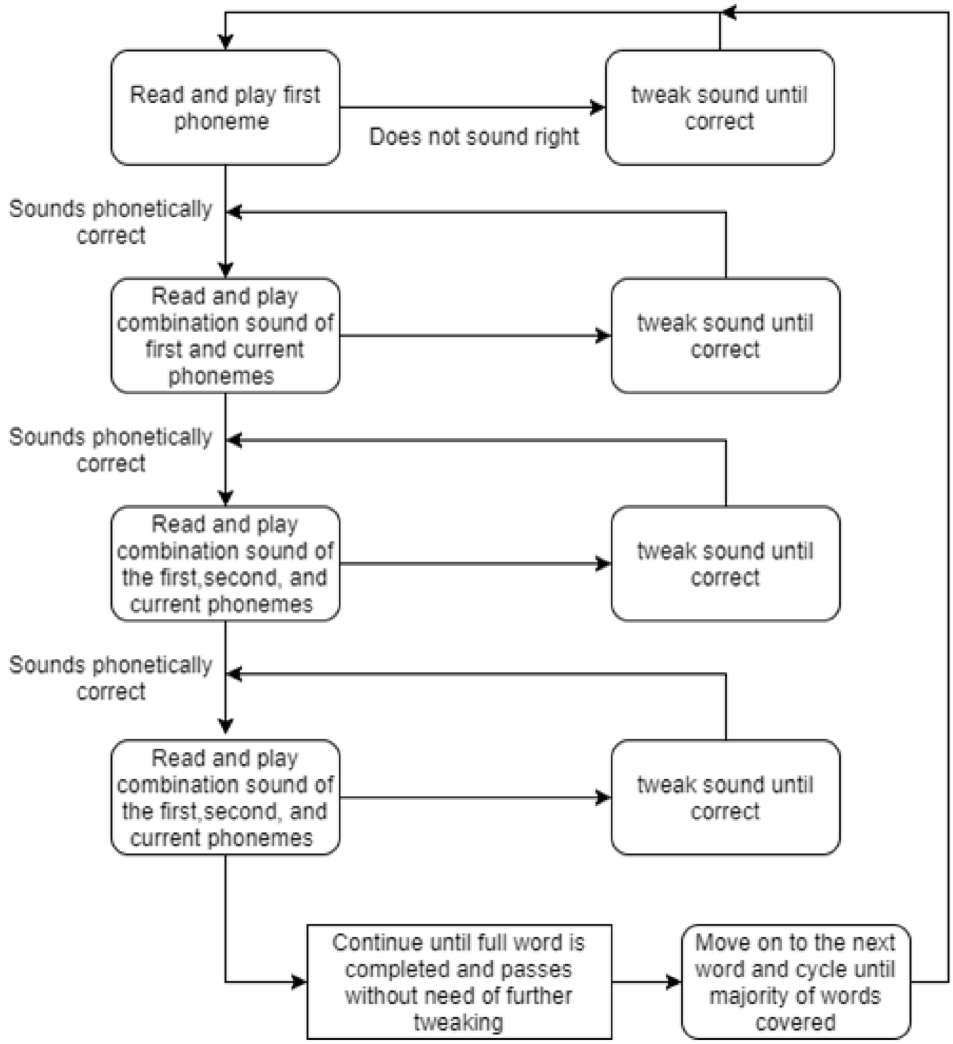


Figure 58 Block diagram for performance testing

8.2.7 Usability Testing

Usability testing is performed to the perspective of the client, to evaluate targeted questions such as, how user-friendly is our device to various ages? Can someone with little to no experience in modern technology be able to grasp the simple concept of how it performs? Will instructions be needed, or will the display be simple enough to operate without any procedures verbally or written? After learning how to use, how quick or slow is the learning scale and how proficiently will the user be able to perform? Is the design aesthetically pleasing? This testing falls under the class of black testing. We want to make sure we have covered all aspects of audiences to ensure we have achieved our simplicity requirement all while upholding maximum performance.

8.2.8 Acceptance Testing

Acceptance testing is primarily done by the users or targeted audience to guarantee that the delivered final product satisfies the requirements we have set out and functions to a satisfactory level that pleases not just us but the targeted users as well and performs as they expected.

8.2.9 Regression Testing

Regression testing is the process of performing test after the modification of a system, component, or a group of related units to guarantee that the modification is working the way it is intended and is not damaging or hindering on other modules to produce unexpected results. It is important to perform the test directly after altercation and before attempting to apply another modification.

9.0 Administrative Content

This section is the outside content that the team has used to stay organized, on budget, and within project roles. This is the general area that overviews some of the team dynamics and organizational data. Administrative content outlines the lifecycle of the project, while giving a general overview of the team milestones, PCB system, vendor, and budget. It will also discuss some of the problems the team ran into when designing the PCB and the future scope of the project looking into the future of what Funetics could achieve.

9.1 Speech-Language Consultant

Since the Funetics team is comprised of two computer engineers and two electrical engineers, there were many aspects of our design that needed a qualified consultant to oversee the speech and language portion of Funetic Board. Emily Chesley, a relative of teammate Meychele Chesley, was chosen as the project speech-language consultant. She received her undergraduate degree from University of Central Florida, she is also currently working on her M.S in speech-language pathology at Florida State University.

She has provided her expertise in many aspects of our design, ranging from selecting the specific sounds that Funetics implements, to making sure our design can be executed properly to reach users with a range of different impairments. She has made it possible for Funetic Board have the impact and educational capabilities for users of all ages and backgrounds.

9.2 PCB System Overview

The PCB design will follow the design of the Arduino Uno board plus some additions. Since the Arduino Uno design is available to freely use this will save time when designing the PCB for this project. The Arduino Uno design will be kept the same but have the audio amplifier portion added to it to allow for quality audio output to be played. The ATmega328 microcontroller will be responsible for executing the instructions in the programs. Our PCB will essentially be a hybrid of the systems that we need in the Arduino Uno and the audio PCB we have designed from different reference designs.

In Senior Design I, we will be using the Arduino Uno and wave shield to for testing and starting out. Funetic Board could be fully functional with those two development boards, thus, once we get the design fully operational on the development boards we will transition into our custom Funetic PCB design. We are using this approach due to the complexity of both the power board and audio amplifier design. Testing will be much easier with boards that we already know are fully functional for a control aspect to our experimentation.

9.2 PCB Vendor

While researching about PCB vendors, a few different vendors were analyzed. The PCB design specifications will be sent to the top qualifying prospects. Reading reviews about vendors and talking with previous students that have taken senior design and needed to order a PCB helped with the deciding of the vendor. Another thing that was analyzed when deciding on a PCB vendor was the cost to get the PCB made and shipped.

9.3 Budget and Finance Discussion

Normally when evaluating the cost of a design, the design should be cheap enough that its market price would be comparable to other competing companies. Funetic Board is such a unique and entirely new concept that there aren't many other products out there that quite compare. So, when evaluating a target budget, we thought about what type of customer would be purchasing it, if it were on the market. Since Funetic Board is rather large and heavy, it is not very portable or accommodating for a family home. Thus, it will mainly be purchased by speech professionals or facilities for their classroom. We originally intended for the budget to be $500 dollars but after researching and modeling the housing, it as larger than intended and more expensive to machine.

To save on cost, we will be manufacturing and prototyping Funetic Board at the company where group members Meychele Chesley and Maureen Flintz work, Levil Technology. Levil Technology is a machine and electronic manufacturing facility that will provide all the tools needed for the team to get Funetic Board operational. Levil Technology will be providing tools such as, solder, soldering iron, heating gun, surface mount resistors and capacitors, wires, oscilloscope, voltmeter, and other tools that the Funetic team might need.

Since our housing needs to be machined with a CNC router, this has become the most expensive aspect to our design. Like stated previously, the housing had to be larger than originally intended in order for the board to work aesthetically. Even though wood is fairly cheap, there are specific manufacturing techniques that are needed to complete the housing. We will be using a woodwork manufacturer called Sils Woodworks, guaranteeing that our housing will be machined correctly while also remaining aesthetically pleasing.

Another aspect of our design that needs machinery and can get expensive will be creating the vinyl die cuts for the Funetic spheres. Group member Meychele Chesley already owns a Cricut die cutting machine so we will be able to save cost by not having to purchase or outsource a machine to complete the spheres.

The Funetic Board team is not seeking a sponsor and plan to finance the project by splitting the overall cost to each individual teammate. We originally intended on finding a sponsor, but could not find a sponsor that was looking for the type project we are trying to achieve. If in the future, we can find a sponsor who is willing to support Funetic Board, we will be willing to coordinate a sponsorship for this project.

9.4 Project Design Hurdles

The Funetic team has come across a few different problems when it comes to the project design. The first problem encountered was building the audio PCB to meet the expected sound quality requisites for this design. The first few designs that we had found and came up with, after doing simple testing, ended up making too much noise and having other sound quality issues. Executing a high sound quality design is much more difficult than originally intended. The current audio amplifier design we have now should produce the quality of sound we are looking for, although it will have to go through much more extensive testing in Senior Design II.

When the Funetic team initially imagined the Fuentic Board, we intended on the board being portable and lightweight. After modeling the design in CAD software, we found that realistically it was out of our limits as electrical and computer engineers to make the housing more lightweight and compact. Thus, another hurdle was getting past the new projected dimensions, and making sure the project will not be so bulky that the aesthetic value lessens.

Another main hurdle we encountered was not being able to convey every sound in the English language. We overcame this by making sight cards and a special Funetic reference word bank that the user can manipulate to make key words. We also consulted with our speech specialist to choose these words, to make sure that they are words that many people struggle with to maintain Funetics educational capacity.

9.5 Looking Forward

Funetic Board has a bright future, if it was manufactured past the prototype phase is could be sold to elementary, middle, and even high schools of any kind. It also could be used in any private speech pathologist facility. It could even be implemented in a home, where a child has a specific speech disability and wants to communicate via our Funetic Board. The Funetic Board concept could also be implemented in an app for users of all ages. If in the future, the housing design became streamlined, Funetic Board could be sold in stores and used as an educational tool for households of all sizes.

10.0 Project Summary and Conclusion

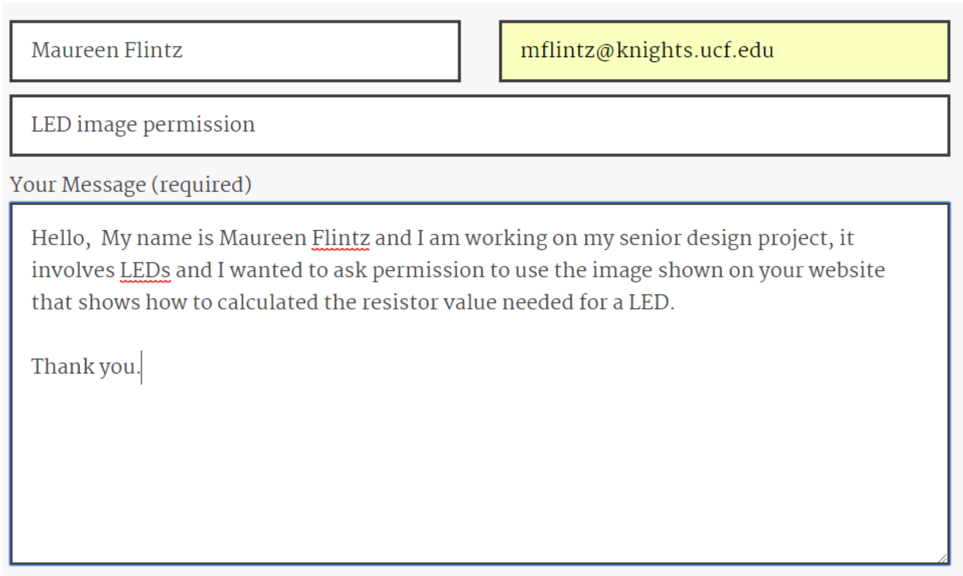
The goal of the Funetic Board project is to create a fun and captivating educational tool that can impact a wide range of people with a variety of different speech impairments. With its bright LED lights, clear loud sounds, and unique hands on user interface, children and adults alike will love breaking down and analyzing the English language in such a creative way. Having a speech problem can impact someone's life in both minor and major ways, and Funetic Board can be helpful to people with different levels of speech impairments.

The Funetic Board team spent the majority of their time researching and designing a system that is capable of quality sound, RFID recognition, and SPI interfacing. Having a limited budget and limited time impacted the project greatly. Because of these limiting factors The Funetic Team has found ways to still have Funetic Board executed but in a low-budget and simplified manner. As the implantation process continues into next semester, the team will need to put their main efforts into sound quality and software timing execution. These are both complicated tasks to overcome but if not executed properly, Funetic Board's use will change drastically.

From this project, the Funetic Board team has learned how to incorporate many different subsystems into one large design. We have learned how to adequately research different parts, comparing and contrasting until the most applicable part is chosen. Concepts such as speech pathology, sound quality, RFID, SPI and PCB design are all completely new tasks learned by the team specifically for the Funetic Design. Working on this project has furthered our knowledge in many ways, mainly hardware design and implementation. This project has also brought us closer as a team, learning valuable communication and teamwork skills.

Moving forward, the Funetic Board team plans to adhere to the milestone schedule discussed in the beginning of the paper. If the project gets finished early, we could easily implement more sounds and even make an app that interfaces with the device. Overall, the Funetic Board has many systems that were once unfamiliar with everyone on the team and was a great choice to not only build something that will further our knowledge in engineering, but also help others in their own struggles.

Appendix A – Copyright Permissions



Maureen Flintz

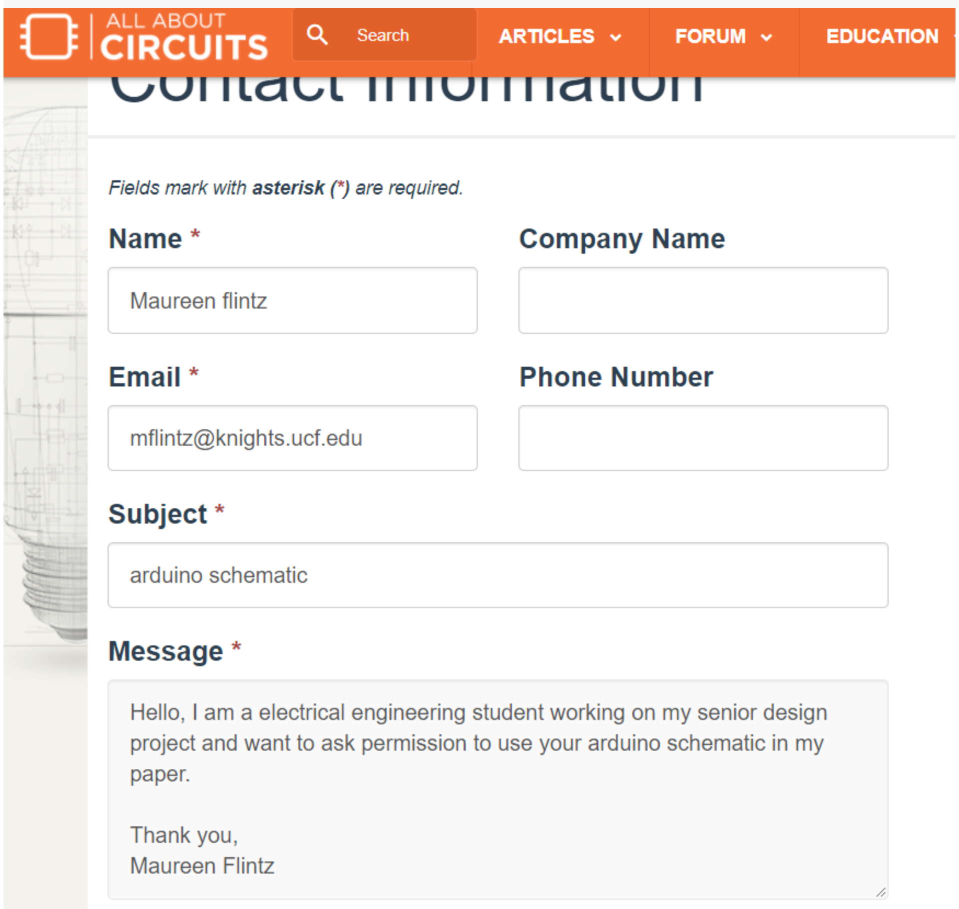
mflintz@knights.ucf.edu

LED image permission

Your Message (required)

Hello, My name is Maureen Flintz and I am working on my senior design project, it involves LEDs and I wanted to ask permission to use the image shown on your website that shows how to calculated the resistor value needed for a LED.

Thank you.



Contact Information

*Fields mark with **asterisk** (*) are required.*

Name *

Maureen flintz

Company Name

Email *

mflintz@knights.ucf.edu

Phone Number

Subject *

arduino schematic

Message *

Hello, I am a electrical engineering student working on my senior design project and want to ask permission to use your arduino schematic in my paper.

Thank you,
Maureen Flintz

Name *

Maureen Flintz

Link to Quora profile

e.g. http://quora.com/profile/Marc-Bodnick, http://quora.com/profile/John-Doe-3

https://www.quora.com/What-are-the-disadvantages-of-lead-free-solder-vs-lead-solder

Details *

Please provide any additional details for your request.

I would like to request permission to use the image that shows two balls of solder showing the difference between lead versus lead free paste. I am currently working on my senior design paper for my electrical engineering degree and in my paper i explain the pros and cons of using lead and lead free paste.

Email address *

mflintz@knights.ucf.edu

E ElectronicsHub.org <elktros@gmail.com>

Yesterday, 12:56 AM

okay. give credits to us by providing our link, you can use it.

Admin
Leona Lee
electronicshub.org
Facebook | YouTube | Pinterest | Instagram

MF Maureen Flintz

Fri 12/1, 8:34 AM

elktros@gmail.com

Reply all

Hello, my name is Maureen Flintz and I am currently working on my senior design paper for my senior year in Electrical Engineering . I would like to request permission to use the image on your page that shows the difference between a microprocessor and a microcontroller. This is the link to the image https://www.electronicshub.org/difference-between-microprocessor-and-microcontroller/ .

Thank you,
Maureen Flintz

AA Angela Avanzino <Angela@jameco.com>
Fri 12/1, 11:11 AM

Hi Maureen,

Yes you may use the images.

Sincerely,

____

Angela Avanzino
Director of Marketing
Phone: 1-650-802-1507 | Toll Free: 1-800-831-4242
www.Jameco.com | www.ClubJameco.com

LOW PRICE LEADER IN POWER PRODUCTS

...

MF Maureen Flintz
Fri 12/1, 8:49 AM
webmaster@jameco.com

Reply all

Hello, I am currently working on a senior design paper for my Electrical Engineering degree. I would like to ask permission to use a image displaying various types of LEDs from your website. The link to the page is https://www.jameco.com/Jameco/workshop/circuitnotes/circuit-notes-led.html .

Thank you,
Maureen Flintz

Ej Ortiz <ejortiz96@gmail.com> Nov 7
to BatteryU

Hello,

working on a research paper and I came across your characteristics table (figure 1) on batteries on your page " http://batteryuniversity.com/learn/archive/whats_the_best_battery " and found it very informative and would like to use your table in my paper as a reference.

BatteryU Nov 8
to me

Hi Ej,

Yes, you may use the material as requested. Please cite sources where appropriate.

Regards,

EJ

Ortiz

Enter your email here*

EJOrtiz96@gmail.com

UCF

Your message*

Hello,
I am currently working on a Senior Design project and found research and photos included here that I would like to get permission to use for my project for citations and references.
Thank you.

CMLOEGCMLUIN

- ABOUT ME
- CINEMA
- VIRTUAL REALITY
- WORDPLAY
- DREAM BLOG
- MUSIC
- VISUAL ART

Leave a Reply

Hello, I am working on a research paper for my senior design class at UCF. I came across the english phenomes by commoness table and found it very useful, and would like to use a screenshot of it in my paper as a reference. Would this be okay? I will be citing appropriately.

Fill in your details below or click an icon to log in:

mchesley@knights.ucf.edu

Meychele Chesley

Website

Circuit Basics

LEAVE A REPLY

Your email address will not be published. Required fields are marked *

Hello,

I am working on a research paper for my senior design class at UCF. Would it be okay to use your LM386 audio amplifier with bass boost figure as a reference design in the paper? The figure will be cited appropriately. Thanks.

MEYCHELE | MCHESLEY@KNIGHTS.UCF.EDU | WEBSITE

Not secure | www.electronicsengineering.nbcafe.in/r-2r-ladder-da-converter/

LEAVE A REPLY

Comment

Hello,
I am writing a research paper for my senior design project at UCF. I am wondering if I can use your binary ladder network figure (the first one listed) in the paper. The figure will be used as a reference and will be cited appropriately. Thanks.

Name *

Meychele Chesley

Email *

mchesley@knights.ucf.edu

← Reply ≪ Reply all → Forward Archive •••

Permission to use diagram - MCP4921

outlook_38D2C9669BF06F5A@outlook.com
6:01 PM

To: university@microchip.com

Hello,
I am writing a research paper for my senior design class at UCF. I am wondering if I could use the block diagram in the MCP4921/4922 datasheet as a figure in my paper. The figure will be used as a reference and will be cited appropriately.

Thanks for your time,
Meychele

Email TI support

Meychele Chesley

[redacted]

[redacted]

[redacted]

Please refresh your page to see changes

* Required

* Issue type

University Inquiry

Part number

LM386

Confirmation email subject line

Permission to use figure in datasheet

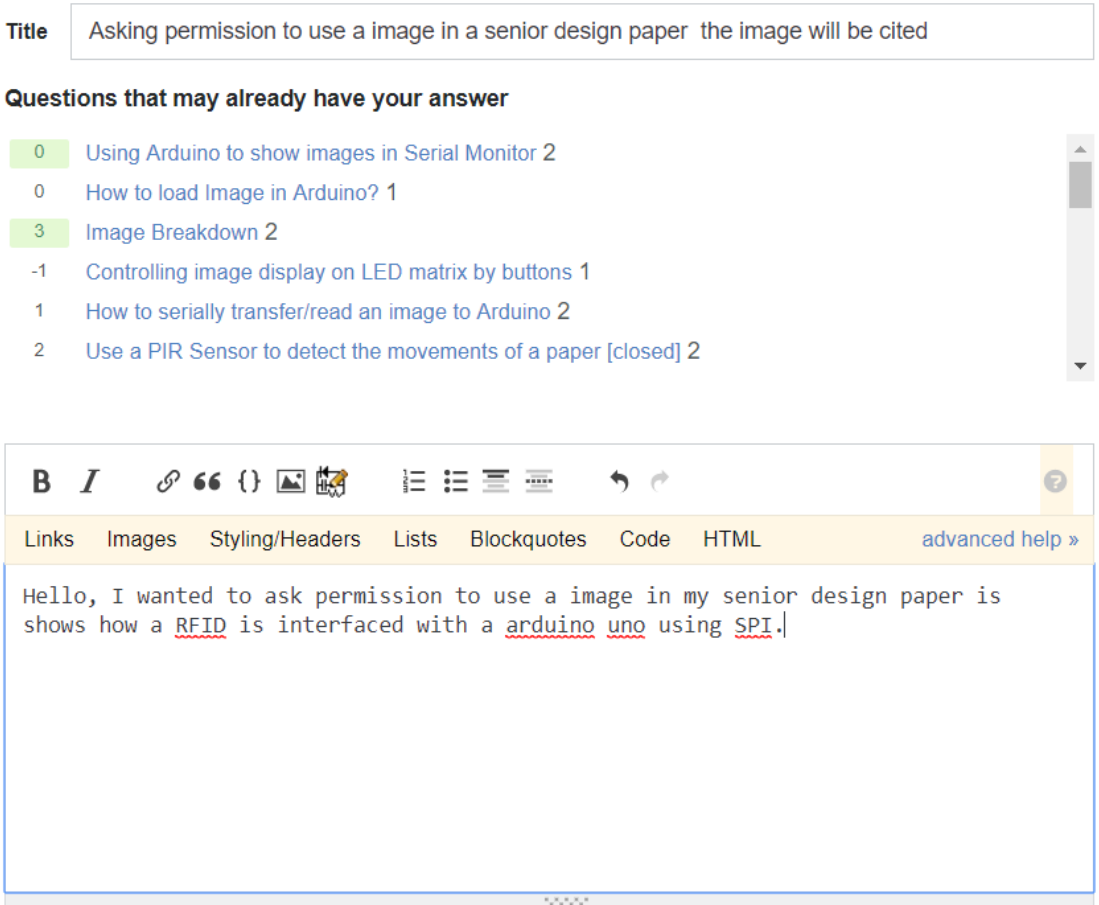
* Issue description (text only)

Hello,

I am working on a research paper for senior design and would like to use the schematic of the LM386 from its datasheet. It will be used as a reference and cited appropriately.

Thanks for your time,
Meychele

583 characters remaining.


Title
Asking permission to use a image in a senior design paper the image will be cited
Questions that may already have your answer
0 Using Arduino to show images in Serial Monitor 2
0 How to load Image in Arduino? 1
3 Image Breakdown 2
-1 Controlling image display on LED matrix by buttons 1
1 How to serially transfer/read an image to Arduino 2
2 Use a PIR Sensor to detect the movements of a paper [closed] 2
Links Images Styling/Headers Lists Blockquotes Code HTML advanced help »
Hello, I wanted to ask permission to use a image in my senior design paper is shows how a RFID is interfaced with a arduino uno using SPI.

Email TI support

Meychele Chesley

[redacted]

[redacted]

[redacted]

Please refresh your page to see changes

* Required

* Issue type

University Inquiry

Part number

TL071

Confirmation email subject line

Permission to use figures in datasheet

* Issue description (text only)

Hello,
I am working on a research paper for senior design and would like to use the schematic of the TL071 from its datasheet. It will be used as a reference and will be cited appropriately.

Thanks for your time,
Meychele

576 characters remaining.

Appendix B – References

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Appendix C – Abbreviations

MCU – Microcontroller
SD 1 – Senior design I
SD 2 – Senior design II
NFC – Near Field Communication
RFID – Radio Frequency Identification
PCB – Printed circuit Board